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THE
ORIGIN AND NATURE OF LIFE

BY
BENIAMIN MOORE, M.A., D.Sc., F.R.S.

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LL.D., F.B.A.

PROF. J. ARTHUR THOMSON, M.A.

PROF. WILLIAM T. BREWSTER, M.A.
(COLUMBIA UNIVERSITY, U.S.A.)

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THE ORIGIN
AND NATURE
OF LIFE

BY
BENJAMIN MOORE

M.A., D.Sc., F.R.S.

Johnston Professor of Bio-Chemistry,
University of Liverpool

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THE ORIGIN AND NATURE OF LIFE

CHAPTER I

PHYSICAL AND PSYCHICAL EVOLUTION

WHETHER the human mind be dealing with the problems of some branch of natural science, or constructing systems of ethics, philosophy, or religion, it is equally essential to clothe its thoughts in language derived from those things in the material world which appeal to the human senses.

The extent and accuracy of our knowledge of external phenomena increase all the time, and it is this increase of knowledge which makes all science progressive.

True religion apart from dogma is the sublimed essence of the knowledge of the highest things in the world, and in itself is never opposed to natural science; but when there is error in men's conceptions of religion or of natural science, then there may for a time appear to be a conflict. But as time advances

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and thought on both sides becomes clearer, it is found that both religion and science stand out as a united whole purified by the removal of the dross and more brightly radiant in intrinsic beauty and loveliness.

Seventy years have elapsed since Macaulay made his famous pronouncement in his remarkable essay on Ranke's "History of the Popes," that neither natural theology nor revealed religion is a progressive science, and the advances in religious thought and scientific knowledge during those seventy years have alike refuted his position, and shown that religion as much as any science is progressive in its nature, and that man's religious thought broadens with the flight of time.

When new scientific facts are suddenly thrown in amongst old pre-conceived ideas of divinity, there may at first appear discords, and zealous champions of natural science, and of religious knowledge, fly to arms and indulge in acrimonious polemics; but, as time advances and things that are crude and adventitious are thrown away on each side, it is discovered that science has added a new beauty to religion, or rather revealed a beauty that was there all the while, but concealed by misconception, or by lack of knowledge.

The presence of this progress and organic evolution in religion, ethics, and social science, cannot be doubted by any thoughtful person of middle age who will cast his mind back on the change in religious thought and teaching during his own life, and if ampler confirmation be required, it may readily be obtained by comparing a volume of sermons, or some other form of theology, written say a hundred years ago with a modern work. If a similar appeal be made in the case of natural science the like result will be obtained, and to-day we laugh at the naïve conceptions of natural philosophers of a century ago, just as much as we sometimes shudder at the religious ideas of their contemporaries who invented theological dogmas which we have now buried in a merciful oblivion.

But the eternal truths of science and religion were the same one hundred years ago as they are to-day and as they will be one hundred years hence, both realms of knowledge, as well as our inborn desires to penetrate their mysteries, are a part of the great plan of creation, and in their intrinsic laws remain the same "yesterday, to-day and forever." It is our knowledge and powers of conception that have changed and not the eternal verities.

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Looked at from this point of view the differences between natural and, so-called, revealed religion disappear and every discovery of science becomes revealed religion, and the scientific discoverer the minister of the Infinite. Should such a discovery later be replaced by something higher, or receive limitations as the result of later discoveries, then it is modified or disappears from revealed religion just as much early legend that was purely mythological in religion has had to disappear with the advance of natural science, although regarded by earlier theologians as an intrinsic part of revealed religion in the narrower sense of the word.

Such reflections as the above might seem ill-chosen in introducing a work on natural science, were it not that this volume is intended to deal with a subject which is supposed to be shared by theologian and natural philosopher, because it possesses both a physico-chemical and a psychical side. The natural philosopher is studying the machine which evolves that set of energy phenomena which display the mind, and hence although working at a different level may be dealing with matters of interest to the psychologist and theologian. It must frankly be admitted on both sides that this interpenetration does

exist and cannot be dissolved. The worker on the higher and more difficult psychical aspects must pay attention to the findings of the bio-chemist and physiologist, for he may be quite certain that anything less certainly proven at a higher level which runs counter to chemistry and physics will in the end be found to be erroneous. Similarly, the chemist on his part must not allow his vision to be narrowed, and refuse to believe that factors exist which do not come within the problem of his science, so long as they are not really impossible as a superstructure to his basis when his science and that of the psychologist have become more developed. The incompatible on both sides must be examined and investigated until incompatibility has disappeared, because it is certainly due to error or incomplete knowledge on either side, or on both, but outside this limitation each worker must have perfect liberty to pursue his investigations. This plan is the one seen daily in operation. One scientific worker, taking certain things for axiomatic, is at work at a level to which the scientists of another group have not yet built up. The temple of knowledge is grand enough in its superb proportions to find working room for all of them, and the work

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yields pleasure at its highest to all the artificers.

It would never have done for the physiologist to remain idle till the chemist had discovered the nature and properties of all the chemical constituents of the body, nor for the psychologist to abandon the study of the mind until the physiologist had supplied him with a complete physical basis for his work by elucidating the minute structure, relationships and simple reactions of the nervous system. It would have gone hardly with the world's invalids, as also with the health of the whole community, if the physician and surgeon had waited for the completed sciences of chemistry, biology, physiology and psychology before tackling the problems of disease, although every year they stand indebted for further advances to discoveries made in these cognate sciences.

Such reasoning extends right up into the highest regions of human thought and activity, into the study of the so-called humanities, history, sociology and religion. Each one is progressive, all are living and moving, discovery in one affects others, and all must be studied simultaneously, each by its own host of votaries. Very often the exclusive study of one branch of knowledge at close quarters

causes the student to lose perspective and deny the importance, or even the existence, of other knowledge. Such a person is merely uneducated or it may be is incapable of education through some natural defect. He resembles some one with a lack of appreciation of harmony who cannot understand why another person enjoys music, or one who, short of actual colour blindness, cannot appreciate pictures, or the glorious beauty of Nature in scenery, or in the forms of living plants or animals. The assertions of such a person should not irritate the man who has been gifted with higher sense, he is rather to be pitied, helped as far as possible, and taught like one who is partially blind or deaf. It is also to be remembered that such a defective person in one direction may be so endowed as to be a genius in another, and that the true action of average humanity ought to be to accept his genius while discounting and pardoning his eccentricity. The world has lost much invaluable service in all realms of thought and action, and some of its brightest geniuses have been outlawed or slain as martyrs, simply because of the associated eccentricity accompanying genius which the average mortal regards as madness or crime.

As an example of the effects of narrow

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study there may be taken the statement that the life-processes contain no problems, save those of chemistry and physics. When this statement is examined rigorously it will soon be seen that it cannot be passed off as a complete expression of all human philosophy. Our thoughts must obviously be something different from chemistry and physics since they can live and re-awaken thought in others centuries after our demise, but in the production and transference of such thoughts between speaker and auditor, or writer and reader the basis all the time is obviously physical and chemical change or reaction in the brain, special senses, and other parts of the body. Each link in the chain may be physico-chemical, but the chain as a whole, and its purpose, is something else. As well, in a concert, might it be said that each musical note was physico-chemical and that the blending in time and pitch were purely physical factors which gave rise to the pleasure; but there is the mind of the composer, the performers and the auditors, and there is something which takes cognizance of the whole effect, and to say the very least of it the physicist and chemist have not yet explained it, and have proven nothing more than that the physico-chemical processes are

the vehicle of the whole thing, the instrument upon which something is played.

The higher the ascent that is made in the scale of human thought and activity and the closer approach that is made to those things, which, in so many civilized races in common and yet independently, have been regarded as divine or sacred, the clearer does this distinction become.

It is well known to us now that the love of order and beauty as we perceive it, is a part of all nature, and our love of the beautiful is part of the evolution which was shaping and forming beautiful things in creation long before man was there to appreciate them and take his part in the scheme of creation, but what is the exact relationship of chemistry and physics to this innate love of beauty and science? When we know more chemistry and physics we shall understand it better, but it is as yet too early to exclude all but chemistry and physics from the scheme of our philosophy.

The study of our social relationships to our fellow-men again furnishes an example of the relationship of chemistry and physics to psychological and religious problems. Nearly all social problems have a material basis, but the interconnections and the factors which sum up and urge us forward to solve such

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problems, and in so doing develop the highest and noblest instincts—these are something more than the purely physical.

The material substructure must be there to render thought possible, and as soon as that substructure develops it becomes inhabited by certain forms of energy which become more complex in their manifestations as the substructure evolves. Structure and function react upon each other as evolution proceeds, and there is throughout a continuity, but it is questionable if anything is gained by assuming, while our knowledge is still so incomplete, that matter may not follow new laws as it becomes more complex, for new forms or manifestations of energy may arise which were impossible or lacking to the simpler forms of matter. Care is needed that in entering into disputations as to whether it is not all chemistry and physics, terminology is not becoming confused so that the dispute is only over terms instead of over things.

A remarkably clear side light is thrown upon the problem if, instead of passing upwards in complexity of structure of matter towards life, consideration is given to the energy changes which occur when matter becomes more simple in structure. This will be dealt with later in greater detail when

inorganic evolution is considered, but here, it may be remarked that the whole of the wonderful new land discovered by radio-activity has revealed to us that when matter is radio-active it possesses new energy properties which are not found elsewhere. Radio-active particles which possess less than one-thousandth part of the mass of any elementary atom previously known to us, possess a relatively enormous store of a new type of energy with a set of properties entirely its own yet bearing relationships to other well-known forms of energy, itself derivable from these well-known forms, and re-convertible back again into them. If matter in simpler forms than the atoms to which we have long been accustomed possesses new, strange forms of energy, is there any need to shut our eyes to the fact that as matter increases in degree of complexity and eventually becomes the basis of life it will begin to manifest new energy properties and give rise to energy-transformations and phenomena such as are never seen in inorganic nature ?

As will be shown in the development of the subject such energy manifestations characteristic of life do occur and form the special subject of study of the bio-chemist and physiologist just as radio-activity and the

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laws of inorganic chemistry furnish a life-study for the chemist and physicist. Moreover, there is no breach of continuity between the inorganic and the organic, or any need for the postulation of an abrupt act of creation of the organic from the inorganic at some definite past moment in cosmic history which has never been repeated.

There exists a whole territory of approach between the inorganic and the organic in what is known as the chemistry of the colloids, and it is a most remarkable thing that this great fact, which is only now beginning to be appreciated, was perceived and clearly set forth by Thomas Graham, the pioneer worker on the chemistry of the colloids, to whom we owe the introduction of the term colloid and many master discoveries in this most interesting zone of chemistry which now claims hundreds of ardent workers all over the world.

The study of colloids has not only had profound effects upon our philosophical conceptions of chemistry; it is producing enormous changes in many fields of industry, for colloids are amongst the most important of the chemical substances utilized by civilized man, and in the future the study of the properties of the colloids found in living

structures will revolutionize our knowledge of biology and physiology, and cause astounding advances in the applied medical sciences.

The mystery of life is often spoken of as if it were the crowning mystery of all things, and indeed it has its wonderful secrets like all the natural phenomena of the world. But the riddle of the universe lies much deeper than life. The evolution of life from inorganic materials is only one stage more mysterious than the evolution of any one form of matter from another, for in fact it is of that type, and the new energy changes are little more startling than those which occur at other levels in the chain of creation. The fundamental mystery lies in the existence of those entities, or things, which we call matter and energy, and in the existence of the natural laws which correlate them and cause all those things to happen which the natural philosopher observes and classifies and correlates, but cannot explain in one single instance.

The scientist has perceived through his senses the existence of certain things, and that by following certain laws a world including himself is evolved. He has proceeded to enunciate and work out the simplest system which will correlate all these things; and all scientific work consists in extending this sys-

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tem, filling gaps in it, and elucidating apparent exceptions. All this is of the highest value to him, and to the higher processes of evolution in which he himself is a conscious factor. The highest advantage accruing to him is the study itself and the means which arise incidentally to the study of enlarging its scope and making new advances. Compared to this higher pleasure the material advantages are but trumpery, and too often act as an enervating influence on the less studious portion of humanity, or form the means of degrading and enslaving the many millions who do not possess enough scientific knowledge to arrange how to share the material benefits so that they may be a blessing to all instead of a curse alike to those who possess too much and those who possess too little.

Despite these material advantages or disadvantages to the world at large springing from his work, the true scientific pioneer, whom we may regard as we choose either as the genius or the genie of higher evolution, is irresistibly impelled by his natural endowments to go on cataloguing, and arranging, and investigating natural phenomena, and it is well that we should consider at the outset what are the apparent limitations of the age

upon such labours, without attempting to fix any impossible gulf which some superman of future evolution may not be able to pass over.

The scientist after he has collected a sufficient number of accurate observations, may discover an existing law of science which enables him to correlate phenomena, and in a secondary sense explain them; but he never discovers the primary cause that has set his law in existence. His observations have taught him that something which he names matter or material exists in many various forms, deeper study has shown him the relationships of these forms to one another and enabled him to reduce the number of primary forms of matter to a small set, which for the time he called chemical elements, and from which he has been able by appropriate unions to construct hundreds of thousands of derived forms. Even now he stands on the verge of the discovery that all his elements are derived from one form of stuff only, which may not be matter itself, but when tenanted by something which he has recognised and named as energy becomes converted into forms of matter leading up to those elements which he first unearthed. But as to why all these things happen, or

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exist, he possesses as yet no knowledge. It is just here at this fundamental point that science and religion meet in the minds of most men who have thought deeply enough about the problem, and here, since farther penetration is as yet impossible, it is open to each thinker either to declare he must leave the problem so, or to call in something in the nature of an infinite intelligence which surpasses himself in that it possesses the power of inducing these fundamental properties and activities upon matter throughout all space and time.

The first position never has satisfied, and as evolution advances will still less satisfy the mind, the second position at all ages in the world's history of which we possess any record has led to the evolution of systems of religion. Imagination is as fundamentally important for a student of natural science as for a poet or a devotee of a religious belief. It is by the use of the imagination that science is led on from discovery to discovery, but the essential difference lies in this, that in the legitimate domain of natural science the work of the imagination must be proven by the test of experiment, which alone gives the true clue towards the reading of the romance of science which lies there, written we know not

how, for translation by us. In the psychical world there exists no such touchstone of experiment, and there does exist the fundamental difficulty of building up a system of thought on anything else than a materialistic basis, so that in the last resort the theologian becomes just as materialistic as the veriest mechanician. It is important for the materialist to realize that his methods of experimentation cannot be extended to touch or test things of a purely psychical nature, and it is equally important for the psychologist to remember that he has only so far been dealing with materialistic models, and studying the substructure in which mental acts occur. Neither set of philosophers, whatever their beliefs may be, can prove or disprove anything as to the existence of mind apart from matter, or what are the subtle relationships of mind and matter.

The ordered beauty of the world of Nature suggests an infinite intelligence with powers of action such as no man or other creature possesses, and evolution which was so hotly contested by the theologians of a generation ago, suggests the beautiful conception of continued action, but when man commences to speculate as to the nature of this intelligence which rules the universe, however

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much of a theologian he may be, he is driven back upon materialistic models, and his deity cannot rise above a perfected superman. In the present state of human evolution, even revelation from the deity could not conceivably take any other form than this, for man with such senses and experiences as he has been provided with, could not understand anything else.

Science can readily strip away from any earlier system of religion, mythological accounts of creation which represent the state of natural knowledge when the system was growing, and can disprove or reject accounts of natural phenomena which are now known clearly to be errors, but when this has all been done the real kernel still remains in any religious system worthy of the name. Man is still left venerating the great causes of creation, and worshipping at the shrine of an infinite and all-powerful creator. Nor is it any bar to this worship that he possesses no rigorous proof nor exact knowledge in terms of material things. The mysticism only stimulates devotion, and urges him onwards towards higher realization of divinity and idealization of all that is highest in the deity that he personifies and worships.

To such a worshipper every scientific ad-

vance brings only a more beautiful appreciation of the divine in nature, and he strains upwards towards it in his own life, and is impelled by his religion to a nobility of life and character, which could scarcely arise in any other way.

If this attribute of mind, to recognize something as the highest in the whole range of consciousness which compels the mind towards its highest efforts, exists in millions of the most highly developed of mankind there must be some cause for it other than ignorance. Surely it is part of mental evolution towards the highest—an intensification of that same process which led creation up from undifferentiated matter through the long course of organic evolution to man. Man has now become aware of this organic evolution, and there is a consciousness developing in regard to it and making for social progress, which is rapidly becoming the latest and highest development of religion. Environment acting as a directing and selecting power upon mutable forms of matter, and lasting through long epochs of time finally brought man upon the earth, purely material environment cannot raise him higher, but in religion in the true sense of the word, increased and intensified by a study of the mind, and of our relation-

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ship and duties towards other minds, we see that factor in our environment which will lead us on to higher things.

The fact that the creature actually in process of evolution has gained consciousness of his own evolution will give a definite purpose to his whole social system as a community, and will enormously increase the velocity in future generations of the process of evolution.

Having thus far attempted to define the relationships of the physico-chemical and the more purely psychical processes of living things, the remainder of this volume will chiefly be devoted to describing the chain of evolution whereby the organic originates from the inorganic, and to the nature of the energy exchanges which occur in the living organism after it has evolved.

The value of imagination to the scientist has been mentioned above, and at the outset it was pointed out that in imagining a scientific system to carry him forward from known facts to fresh discoveries, the scientist equally with the theologian was compelled to build upon materialistic models. It follows therefrom that the orthodox scientific beliefs of one generation become, in part at least, the scientific myths of a succeeding one, and that science just as much as religion possesses its

dead mythology. It by no means follows that these myths, of science and religion, did not serve a useful purpose in those days when they were living and powerful beliefs, but, when new knowledge, power and methods arise, they must be cast on one side, and replaced by better machinery to lead to new revelations. They are the scaffolding of the structure in course of erection, and not an intrinsic part or any permanent adornment of it.

CHAPTER II

GENESIS OF ELECTRONS AND ATOMS

At the present moment in scientific history, as a result of a rapid and brilliant series of experimental discoveries which have taken place during the last fifteen years, we stand face to face with necessary changes in our scientific theories, concerning the nature of two things, matter and energy, regarded by our predecessors as definitely settled foundations of all science.

It is not perhaps too much to say that twenty years ago there had developed a cast-iron belief that matter and energy, and these

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alone, were the two fundamental entities of the physical world, and that each was eternal, unalterable, and had existed in fixed amount from the beginning of days, uncreatable and indestructible.

This fixed belief led to many great discoveries, although there is little question that it also delayed and inhibited others by setting up an unwarrantable boundary to thought. The fundamental experimental discoveries upon which these laws of the conservation of matter and conservation of energy were based, still remain intact, and in certain directions potent to lead to discovery. There is no need to abandon them entirely, but recent experiments have shown that they must be modified, and given their limitations, and this defect in the scientific idols, having been discovered, it has become permissible to examine them critically, without being guilty of sacrilege, to discover if perchance any other part than their feet is made of clay. .

To put the case in as simple and non-technical language as possible, matter represents the stuff or structure of the universe, as obvious to our senses unaided, or aided by artificial means, and energy is the activity (or the power to develop activity due to relative position) of the component parts of the stuff or matter.

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The doctrine of the conservation of matter teaches that the sum total of material, or matter, is constant or fixed however it chanced to be or come there originally, and that matter cannot be created or destroyed.

The doctrine of the conservation of energy teaches the same for the activities, or potential activities of matter, namely, that the sum total of the various manifestations of energy is a constant. Energy may pass from one form to another, and the quantity present in any given form may and does vary, for it is the passage from one form to another, which constitutes all natural phenomena; but there is no manufacture or destruction of energy, there is the same quantity of energy in the universe, as was in the beginning, and shall be for ever.

These two great tenets are fundamental in the orthodox faith of the scientific world of our day. Let us for the moment be daring sceptics and examine them.

In the first place the acceptance of these doctrines as absolutely settled, places a limit on our knowledge both of the past and of the future. As regards the past, it becomes agreed that no discovery is possible of how matter originated, or activity in matter came to exist, and in respect to the future, it is

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admitted that all experimentation directed towards production or destruction of either matter or energy must prove in vain. The only reason for setting such limitations to the knowable is that under the conditions of action which at present we know, production or destruction of matter or energy does not occur. If such a position had been accepted in regard to earlier scientific theories, we should not now know many important things which have been added to the common store of knowledge. The acceptance of a completed act of creation would have precluded, for example, our present knowledge of organic evolution, and the belief in fixed quantities of energy and matter equally involves a non-progressive act of creation at some fixed time in the past. The placing of the creative act in the more remote past, or in a fictitious eternity even, does not solve the problem.

The doctrine is precisely similar to the biological doctrine usually expressed by the phrase of Harvey, "*Omne vivum e vivo*" (all life from life), which closes the door to all attempts to solve our special quest in this book by the dictum that life only can come from life, that it never can arise afresh, and so its first origin lies shrouded in the unknowable past.

As a matter of fact, our experimental observations only amount to this, that in the ordinary and common interactions of matter and energy with which physicist and biologist have hitherto dealt, these laws hold, but we must not allow our naturally great respect for them to close our eyes to the fact that outside these limits, in types of reaction which are just beginning to dawn upon us, these laws, while still holding in a manner, may be so varied as to give room for the inception of both inorganic and organic evolution.

By expenditure of energy in formation of matter from something less complex than matter, or by the setting free of energy at a high potential (or power) due to destruction of matter, the problem of creation may be reducible to simpler terms. Experimental evidence to the exclusion of such a view does not exist, and traces of evidence are lately beginning to come into view, which are highly suggestive of continuous present-day creation of matter at the inorganic level, and of creation of life from inorganic materials at the organic level.

Again, by an extension of the doctrine of the conservation of matter, it was, until quite recently, held that there existed a definite number of primary forms of matter amounting

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to about eighty in all, which were, and are, called the chemical elements. These forms could not be resolved into anything simpler by known chemical reactions, and for this reason, indeed, were called elements, and by combinations of these amongst one another, all chemical compounds were formed. The amount of each chemical element was fixed and inviolable, and that same amount, always had existed in the universe and always would exist. The evidence for this view was just as good, and no better, than that of which we stand possessed for the doctrine of conservation of matter as a whole, namely, that however the element might be transformed and disappear into chemical combination, by the application of appropriate chemical means exactly that amount of it was recoverable again. In all chemical reactions not only did the total masses, as measured by weighing the reacting substances, remain constant so demonstrating the law of conservation of matter, the total mass of each element also remained constant so demonstrating the law of conservation of the elements.

But it has recently been shown experimentally that matter, which by all criteria must be regarded as elemental, in the chemical sense, is in certain cases so endowed with peculiar

energy properties that it is slowly breaking down into entirely different elements, the process being so slow that centuries of time are required for any appreciable breakdown. At the same time enormous quantities of energy are set free. Here from a chemical element, new chemical elements are being formed, and from a chemical element, energy in immense stores is being set free.

The old doctrine has had to give place as a result, and in its stead we now believe that each chemical element represents a more or less stable position in the charging of matter with energy. Those elements which are called radio-active and are continually breaking-down as described above are unstable, and break down spontaneously, while other elements are so stably related to their energy content that no means that we at present know how to apply are capable of disrupting them.

If these things happen the view becomes opened that by energy discharge the most primal matter may possibly be thrown into something which is not matter, in the usual sense of the word, and lacks those criteria by which we appreciate matter, and if this be possible then by attaching energy to this precursor of matter, it becomes possible to

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create matter. Thus the position is arrived at that instead of matter and energy being fixed in amount, and always conserved, they are mutually convertible into each other, as soon as we have discovered the appropriate mechanisms for the purpose.

Again, energy is usually divided into two main varieties, each of which possesses several forms, these varieties are termed kinetic energy and potential energy. Kinetic energy is energy due to motion, either of a large body as a whole, or of the atoms or molecules, which form the minute mechanically indivisible portions of matter, while potential energy is energy due to the position of portions of matter in relationship to one another, and here again the matter may be in larger masses, or may consist of molecules or atoms. Examples of kinetic energy are such as (a) large bodies in motion; (b) heat; (c) light; (d) electricity; (e) radiations of many kinds; (f) the molecular motions of a gas, liquid, or solid; and (g) the motions of constituent atoms of a molecule in relationship to one another. As examples of potential energy (in which motion does not come in) there may be quoted (a) bodies raised above the earth's surface, either solid, or fluid, like water in a reservoir, or gaseous, like barometric differences

in pressure ; (b) magnetic bodies at rest near a magnet ; (c) a coiled spring ; (d) chemical energy due to juxtaposition of molecules or atoms, such as is typically seen in a high explosive, but all chemical substances possess such potential energy ; (d) the heat which disappears without change of temperature when a solid turns into liquid, or a liquid into gas, as in the formation of water from ice or steam from water, this is called "latent heat," but is really not heat at all ; (e) surface tension, such as is seen in a soap-bubble, or at any interface at rest between two dissimilar forms of matter.

These two lists are not exhaustive but are intended to show two things, first, the large number of discrete forms of energy which exist, each with a set of natural phenomena of its own, and, secondly, how completely different the first set of forms of energy termed kinetic are from the members of the second or potential type. The first are forms of activity, the second, forms of passivity, but a definite measured amount may pass from any one form to another, and in the exchange there is never any gain or loss in amount, but always an exact balance. One passive form cannot pass into another passive form without intermediately passing through

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an active form, and although it might seem possible for one active form to pass into another active form without the intermediation of a passive form, as a matter of fact, in nature, this rarely or never occurs. Some intermediate change in position of atoms, molecules or large masses toward each other is always involved, which means a temporary development of latent or positional energy. An energy transformation involving two types of energy only, is unknown, and usually, intermediately at any rate, many types are produced in any reaction.

If regard be paid to the nature of the forms termed potential energy it becomes obvious that they are not really forms of energy at all, but only potentialities for the development of energy. The water in a reservoir, as a still mass does not really possess energy, it only acquires energy as it runs down hill, and it is only confused thinking which has led to the term potential energy. It would be very much clearer to recognize that there are two qualities, *energia* and *potentia*, and that it is the sum of these which is constant or conserved. When this has been done it becomes discernible that all forms of matter, whether elements or compounds, may be various forms of *potentia*, in forming which *energia* may

disappear, and in disruption (as in radio-activity or in electron formation) energia may reappear. As the result of this the real conservation law becomes the constancy of energia plus potentia.

But if there is movement something must be moving, a simple fact which appears to have been forgotten by some philosophers who have attempted to get rid of matter altogether by stating that it is only vortex motion. Something must move in the vortices or, in other words, there must be some precursor of matter which is converted into matter when it becomes inhabited by energy.

Such a precursor may well be the ether, or æther, which has had to be postulated to account for the transmissions of energy which occur through vacua, such as a vacuum bulb carrying electric radiations and radio-active discharges and radiant heat and light, or, the interstellar spaces such as that between the sun and earth which carries the enormous flood of energy as light and heat to supply nearly all our sources of terrestrial energy.

If it be supposed that this ether is lacking entirely in the properties of mass, it is difficult to see in what terms a given quantity of energy in transit through it can be expressed, and a conception is created of energy entirely

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disembodied, so to speak, from matter, which is just as difficult a conception as a disembodied spirit, or a soul away from its body.

In what way, then, it may be asked, does ether differ from ordinary matter? Recently, it has been discovered that the particles, or electrons, discharged from the negative pole or cathode of an X-ray bulb, or the particles thrown off almost with the velocity of light from radium are so minute that they possess less than a thousandth part of the mass of a hydrogen atom, which disposes once and for all of the supposition that the chemical atoms are ultimate divisions of matter, and suggests that atoms are built up of electrons. Now, if it be supposed that ether is either non-particulate or made up of particles of an infinitely lower size than electrons and devoid of energy, and that the electron is the first stage in the building up of matter, a hypothesis is supplied on the simplest basis yet attained for placing in one long chain of continuity both inorganic and organic evolution, and also for the inclusion of many outstanding facts of the new science of radioactivity. Also, the reason for one interesting fact regarding energy transmission by the ether becomes obvious, and that is that all

wave-motions are transmitted by it with the same velocity as that of light.

Given a highly enough concentrated source of energy, it is readily seen that those forms of matter of lowest atomic weight may be formed out of the ether, energy disappearing as kinetic energy and appearing as potential energy, or potentia of the atom.

Astronomical physics teaches us that just such elements are to be observed in the hottest suns and in gaseous nebulae, and it may well be that here we see to-day matter being created, and a varying balance established between energia and potentia, which may, through the long chain of events of increasing chemical complexity, followed later by organic complexity of living organisms, lead to an inhabited world.

It is to Greek philosophy that science owes the conception of matter being indivisible below certain limits, an idea which, at a certain stage of the development of modern chemistry, led to so many brilliant experimental discoveries. It was, however, the English chemist, Dalton, who gave the ancient philosophical speculations a sound foundation of realized fact upon which the enormous superstructure of chemistry, as it is known to-day, has since been built up.

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This foundation is none the less firm because it is now realized that these indivisible atoms uncreatable and indestructible, which Newton supposed to be turned out completely formed by the Creator in the beginning of things, are themselves composed of thousands of smaller particles. It is only necessary for the atomic basis to our chemistry to realize that the atom, just like the chemical molecule at a different stage, or the fixed organic species of the biologist, is a point of stable equilibrium in upward evolution. Between each two such points there lies a region of unstable equilibrium, and as matter becomes more charged with energy, surgings and transformations occur, and in the greater number of cases when the cycle is complete, the matter drops back again to its stable point. But occasionally when a supply of energy at high-potential, or concentration, is available, there is a huge wave of uplifting which carries the matter involved over a hill crest into a higher hollow of stable equilibrium, and a new type of matter becomes evolved at the expense of kinetic energy passing over into latent energy or potential. The process may be reversed, of course, and here, matter at a higher elemental level may be decomposed, setting free energy, as in radio-

active decomposition. The Daltonian atom is thus only stable and indivisible within certain limits of experimentation.

As the atomic weight of the atom, in Dalton's sense, goes on increasing, its content of energy per unit amount of matter is heaped up, and a limit of atomic stability is reached as the atomic weight increases. This is shown by the fact that uranium and radium, those elements which show spontaneous disruption, are also those with the highest atomic weights, as well as by the converse observation, that in those situations where chemical atoms are probably being created by high tension energy, it is those elements with low atomic weights such as hydrogen, and helium, which are present in largest amounts, as shown by stellar spectroscopy.

It is also a curious fact that there appear to be a series of intervals or levels of stable equilibrium in the building up of the elements, bearing a superficial analogy to musical octaves. With approximately equal additions in the atomic weight, there are recurrences of the same chemical properties in the elements so that the majority of the known elements can be arranged in groups or periods according to what is known as the periodic law. So completely does this law run through the

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whole scale of the elements that it has been the means of discovering many previously unknown members. The properties and general characteristics of a missing element have even been fairly well described some years before its actual discovery, much as a biologist might describe a necessary missing species in a biological group of living creatures. As a result, the atomic weights of closely related members of a chemical family do not lie close together; the relative atomic weights of the elements, fluorine and iodine, for example, are as 19 to 127, yet these belong to the same natural group, and intermediately are found chlorine at about 35 and bromine at 87. The interesting point is, that between the level of 19 and 35, in the value of the relative weights of the atoms, the chemical properties of the intermediately occurring elements have run through the whole gamut of all the chemical families which differ most widely in chemical properties, but at 35 the atomic circle has been completed, so to speak, a kind of octave has occurred, and a higher member of the original family has been evolved. Space does not allow us to go into this interesting law more fully here, for information upon it, as also upon inorganic evolution and the constitution of matter and

energy, reference may be made to the volume in this library entitled "Matter and Energy," by Soddy.

These periodic returns to similar properties indicate rhythmically recurring points of stability in atomic evolution. In each series forming a chemical family, instability mounts up and the power of reactivity varies. The members of a group as a whole may be more stable than those of the group above them possessing molecular weights a unit or two higher for each corresponding member, but at length a point is reached in each group where instability prevails, and no higher member is found. Evolution has reached the highest limit to which the stability of the atom will carry it, and the tale of evolution is then taken up by the chemical compound, until this in turn loses its efficiency, and the next stage, namely, that of the colloid, arises.

Although it may only be a superficial analogy, all this bears a curious resemblance to the events which occur quite at the other end of the scheme of molecular architecture. It will be shown later that the unit of living organisms, called the cell, consists of large groups of chemical molecules, built up into a delicately balanced mechanism upon which energy types from the environment play, in

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a loose or labile equilibrium of periodic building up and breaking down in rhythmic flow all through life. Now, as this living cell grows in size there appears to develop a higher potential, or pressure of energy, of its own peculiar type, which renders the cell unstable also, and by the establishment of what are known as dynamic centres, a play of energy transformations starts, causing the cell to divide and give rise to two daughter cells, which are at first stable in balanced equilibrium, and only by growth and accumulation of energy-pressure later reach a stage at which they, too, become unstable and again divide. Also, in a complex many-celled organism, there are groups of cells much like the periodic groups of the chemical elements. Some cells are permanent or stable, and do not divide throughout life, at any rate after the full size of the individual of which they form a constituent part has been attained. Their period of stability is the same as that of the whole animal. Other cells are most unstable, with energy content reaching a maximum and leading to cell-division at frequent intervals; such cells as these are many times formed, and perish, in the life of the animal.

Incidentally it may be pointed out that it is this varying stability which determines

the cycle of life of the individual. There is a popular fallacy in lay minds that the whole human body is replaced by fresh material in a period which by some whimsical fancy has been fixed at seven years. As a matter of fact, some cells are formed, pass to maturity, and perish almost daily, while others last as long as the animal itself. Many of these latter cells form master-cells of the body, of vital importance, and their decay determines the downfall of the whole vast community. Such cells are to be found in the brain and other parts of the central nervous system, in arterial walls, and in mechanisms which control the heart. As age advances the work of these, and other cells, alters, and chemical products are thrown out and accumulate which sow the seeds of decay. Decline and death are accordingly part of a normal process just as much as birth and growth are at the early parts of the course of life, and, so far as our present knowledge leads us, all we can hope for is by watchful care to prevent earlier decay by seeing to it that these delicate mechanisms are not clogged and poisoned by effete products of a poisonous nature manufactured by wrongful habits of life, either in the body itself, or added from without by unsuitable nutrition, or the invasions of

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disease. Even this much would be a great triumph, for it lies within our power as a race practically to abolish infectious diseases and wrongful habits, which are responsible for half the deaths, and four-fifths of the disease and suffering which afflict humanity.

After all, it is the happiness of health during an allotted span rather than mere length of days that is the greatest gain. The suffering entailed by disease during life is a real evil compared with which death at a ripe old age is only a chimerical misapprehension.

Returning to the question of the atomic constitution of matter, it may be pointed out that the view that matter which enters into chemical combinations such as form the inorganic constituents of the earth and the living bodies of plants and animals, is particulate, and built up by unions in varying combinations of eighty or more chemical elements, does not exclude the view that the remainder of space is filled up by non-particulate matter of a certain density, but possessing no weight because it represents the zero of density, or mass, and cannot be separated or weighed. There exists from this point of view no vacuum in space, and the completest vacuum known is that which contains only this non-particulate material, or luminiferous

ether, from which by the agency of energy, giving to it stable forms of motion, particles can be formed. Ordinary ponderable matter consists of solutions, or suspensions, in this continuous imponderable matter, and it has been seen that the transmission of energy through space has already made the postulation of such a medium necessary for the physicist.

The study of radio-activity has disclosed intermediate stages between the chemical atom and the unformed pre-matter, or luminiferous ether, which are of high interest from the point of view of evolution.

When the different types of radio-activity produced either by an X-ray tube or a radioactive substance, such as a salt of uranium or radium, are examined it is found that these can in each case be resolved into three types, which are distinguished by letters of the Greek alphabet as alpha (α), beta (β), and gamma (γ), radiations respectively. They are distinguished, amongst other things, by their relative penetrating powers for substances such as the metals which are opaque to radiant light or heat. The metal aluminium is used as a standard, and it has been found that while the alpha rays are readily stopped by a piece of aluminium leaf of 0.05 of a milli-

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metre (or about 1-500th of an inch) in thickness, it requires 5 millimetres of aluminium to get rid of the beta rays nearly completely, and a column of about 50 centimetres, or twenty inches, in English measure, is calculated to be necessary for the absorption of gamma rays. The relative penetrating powers are thus approximately as 1 : 100 : 10,000.

While the alpha and beta rays consist of minute particles, the size and energy content of which can be accurately measured, and their actual mass determined, the gamma rays are waves or disturbances in the ether propagated in irregular pulses or surges with the velocity of light.

It is the alpha and beta particles which interest us chiefly here as being the initial stage in the synthesis of matter, and the commencement of that long train of interplay between matter and energy which leads up in increasing complexity of molecular structure and attendant change in the inhabiting energy till man is reached.

The beta particle is by far the smaller of the two, and is identical with the electron, or electricity bearer. The form of energy which it carries is electricity, and it is the movement of a constant stream of millions of millions of such beta-particles or electrons

along an electric wire or other conductor which constitutes an electric current. These minutest of all particles may be deflected out of their straight course when they are in motion by a charged surface placed parallel to their flight, or by a magnet, and the course of deflection is the same as that of a stone or bullet flying through the air. From the velocity, and the deflection and other experimental data the mass of the particle and the value of the electrical charge upon it can be calculated. The mass of the electron lies between the $\frac{1}{1000}$ th and $\frac{1}{2000}$ th of that of a hydrogen atom. Since such electrons can be obtained either by spontaneous disruption of radio-active bodies, or, by means of electric energy, from ordinary stable forms of matter, they are believed to be the constituents of ordinary atoms from which such atoms are built up.

The alpha-particle differs from the beta-particle in two chief ways, first, the alpha-particle carries a positive charge of electricity, as is shown by the fact that it is deflected in the opposite direction to the beta-particle by a magnet or an electrically charged body, and secondly, by the fact that it is many times larger, possessing twice the mass approximately of a hydrogen atom. When

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the alpha-particle impinges on solid matter it penetrates some way, loses its electrical charge, and slowly diffuses out again as an atom of helium, one of the chemical elements discovered in recent years.

This helium is the lightest member of the group of inactive gases, of which the first member was discovered as a natural constituent of the atmosphere by Ramsay and Lord Rayleigh, and named argon. Several other members of the group were later discovered, by Ramsay and his co-workers, and helium is probably the most interesting of the group from the circumstances of its discovery and its proven relationship to inorganic evolution. These elements are all very inert gases which have not yet been found in chemical union with each other or with any other bodies. So inert are they chemically that their atoms do not even unite in pairs with one another to form those dual atoms, or molecules, which are nearly always the characteristic form in which chemical elements higher in the scale of evolution unite when obtained in the free elemental form by chemical manipulation. When chemical science does succeed in uniting the members of this series amongst themselves, or causes them to reduplicate, it will probably be found that

what has been obtained is not a chemical compound in the ordinary sense of the term, but a chemical element higher up in the periodic scale, and in all likelihood one of those with which we have long been familiar.

This group of inert gases is conceivably a halfway stage between electrons and ordinary elements, requiring more electrons to be added on, or a union of two such gases, but as yet the necessary conditions are unknown for the energy transformations, or the electronic synthesis.

CHAPTER III

CHEMICAL EVOLUTION IN THE SUNS

THE history of the discovery of helium is one of the most fascinating chapters in the whole of science not merely in regard to the manner in which the knowledge came, but also because of the gradually dawning conviction which it awakened in regard to cosmic synthesis.

In order to appreciate the beauty of the discoveries in stellar chemistry and their relationship to the discovery of helium, some

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short outline of spectroscopic investigation becomes necessary.

Each chemical element as it is raised to an incandescent heat, or becomes radiant in a vacuum bulb through which a high tension electrical current is sent from an electric coil, takes on a rate, or a number of rates,* of periodic vibration of its own of enormous rapidity. As a result of this, the element gives out light of a character peculiar to it. This light when sent through a prism does not form a continuous coloured spectrum in which all colours are represented by light waves of different frequency, but consists rather of a number, few or many, of bright lines. When a spectrum of the incandescent element is obtained by passing the light emanating from it through a spectroscope, a series of distinctive bright lines is obtained which discloses the identity of the element as unmistakably to the spectroscopist as a thumb-print does the identity of an individual. Also, it is known, that if light from another source, such as a gas burner, which would otherwise give a continuous bright spectrum, is passed through the vapour of an element at a high temperature, then that element absorbs just the light which it would itself give out if it were incandescent, as described

above. The result is that what otherwise would be a continuous bright spectrum is now marked by dark lines corresponding to the proper bright lines of the incandescent condition of those elements that the light has passed through.

For example, in the case of the element sodium, which occurs in common salt, it is found that if a spectroscope be turned to a colourless flame such as that of a spirit-lamp or of a Bunsen burner, and some common salt is then volatilized in the flame, so producing a yellow flame, arising from the atomic vibrations of the sodium atoms in the flame, then, in the spectrum two bright yellow lines close together are seen, and this is the only spectrum visible. The reason is that this is the only rate at which sodium atoms produce optical vibration waves. If now the spectroscope be turned towards the sun so as to obtain the spectrum of sunlight, the complementary phenomenon is seen. The solar spectrum consists of a bright band of colour ranging from red to violet, but it is interrupted by a great series of thin black lines, and the point of interest is that two of these lines lying close together in the yellow are in the exact position of the two sodium lines of the sodium flame. In photographic

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language the one spectrum is the negative of the other. The connecting link is found when the light from such a source as a gas burner is sent through hot sodium vapour, for now a spectrum is obtained identical with the solar spectrum so far as these two sodium lines are concerned. The two lines now show up black like two fine ink lines, in an otherwise continuous spectrum.

The conclusion is inevitable. From the white-hot central part of the sun called the photosphere, which would yield a continuous spectrum, the light passes through an upper zone or chromosphere which contains volatilized sodium. By exactly similar reasoning and experimentation the vapour or chromosphere of the sun between the internal white-hot mass and our earth has been shown to contain a large number of our terrestrial elements, some of them in a partially evolved form as proto-elements.

This is the simple basis of stellar chemistry, and for some years now many other suns than the centre of our planetary system have been carefully charted as to their spectra, and classified as to their temperature and chemistry. Terrestrial chemistry has learnt much from these terrifically hot furnaces set in the heavens, giving human observa-

tion an opportunity which would be totally unrealizable on earth of observing the effects of high temperatures and the results upon the constitution of matter. The nebulæ have been similarly studied and chemically classified. At these spots in the universe temperatures exist far exceeding such as are producible upon earth by artificial means, and cosmic history may be studied from which lessons may be derived as to what happened millions of years ago in the history of our earth, and how the elements and substances found to-day upon the earth's crust gradually came to be formed. It is only by supplying this chapter that the mind can be brought into proper training for understanding how life arose, much as one movement in a symphony prepares the mind and senses for, and leads on to another.

In the solar and stellar spectra as photographed and charted by the use of the most powerful telescopes and delicate spectroscopic apparatus, many thousands of lines are visible in definite positions. Some of these lines are very strong and visible with ease through a pocket spectroscope, such, for example, as the double line or D line of sodium, used as an illustration in the description above. Such principal lines starting from the red

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end of the spectrum and proceeding towards the violet are named by the capital letters of the alphabet, and some of the less marked ones by the small letters. Such lines act as landmarks in roughly assigning a position to any given line, or absorption band, in a spectrum of a substance. In this way the spectroscope becomes a great assistant to the chemist, and this is not merely true for the stellar chemist: the physiological chemist or bio-chemist can call in its aid to detect and identify many of the coloured pigments of high importance in the plant and animal world. For example, the red colouring matter of the blood so indispensable to life, which carries round oxygen for the combustion of the nutrition of the living cells derived from the daily food, is identified when placed before even a pocket spectroscope by two specific and distinctive broad bands in the red to the left of the D line mentioned above. When the bio-chemist sees these two bands, he is as certain that he has before him a fluid containing blood, as any one in ordinary life is of the presence of a well-known friend when he looks him in the face.

Just in the same way the stellar chemist can say, there is the set of hydrogen lines, there are the iron lines, and there the well-

marked calcium lines, in the spectrum of a given star or nebula, and with certainty conclude that he is observing millions of millions of miles off, a body so hot and incandescent that iron is not merely molten but vapourized in it, and even beyond that stage is showing certain lines *enhanced*, as it is termed, as on this earth they only can be by a high tension electric current sparked in a vacuum between iron electrodes—a temperature hotter than anything which can be given by the electric arc burning in air. It is just in such hottest suns that the spectra of hydrogen and of the rare gases of the group produced in radio-activity are to be observed in great predominance. Here, evidently, at this enormous temperature, either there is visible before our eyes dissociation of matter into its very first and simplest forms, or, it may be that the available high energy concentration at such a temperature is actually synthesizing and producing from the ether those first steps in the formation of matter. The first process, or that of disruption of matter, forms the orthodox view which at present holds the field, but the second is by no means excluded. The chemist knows well that it is just at the balancing point that a reaction may run in either direction

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varying with a slight disturbance towards synthesis or disruption, and also if synthesis were taking place from the luminiferous ether, it is just those elements that are present in the hottest stars which would be synthesized there. At different levels of temperature in heating, or in cooling, at the same time and alongside of each other, certain forms of matter will be synthesizing while others are disrupting.

So delicately fixed are the positions of the well-known solar lines that a minute displacement towards either red or blue end of the spectrum at once arrests the attention of the stellar spectroscopist. Just as the pitch of a motor horn, or railway locomotive whistle, is higher as the car rapidly approaches the auditor, and falls as the car moves away after passing, so if a star from which the light is coming is approaching the earth with great speed, the optical pitch of each light of every frequency will be increased, and all the lines will be moved slightly towards the blue end, and conversely if the star is receding. The displacement is only slight, for even the high velocity of the heavenly bodies relatively to one another is small relatively to the velocity of light moving at nearly 200,000 miles per second.

Now, on looking at a stellar spectrum such, for example, as that of our own sun, the stellar chemist is soon able to pick out many familiar series of lines as those belonging to well-known terrestrial elements, but in addition to these there are many which are not known terrestrially although the number of these latter is diminishing as research proceeds. Another interesting point is that spectra of different suns differ from one another. Some are quite like that of our own sun, such as the spectrum of the star Arcturus, while others show a considerable difference. If the spectra of a large number of suns are frequently compared until the trained observer begins to grow familiar with them, certain series of lines become associated as being always absent from or present in a spectrum together, and so are proven to be related to a common cause, and probably to belong to the same element present in some suns and absent in others. In this way, some years ago, Lockyer had connoted a series of lines containing three prominent lines and had ascribed these to an element unknown terrestrially, which he provisionally named helium, from its presence in our own sun's spectrum.

For some years this element was entirely unknown upon earth, but after Ramsay had

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discovered the argon group of gases in the earth's atmosphere, he was engaged in a search amongst minerals for evidences of such gases, or any new members of the group, occluded or fixed in the minerals. In the course of his investigations, he undertook the examination of a mineral called *cleveite*, which, when heated, gave off a mixture of gases. When a minute amount of this gas was introduced into a vacuum tube, sparked with an electric coil and the spectrum of the spark examined, there were actually found in the exact positions the characteristic lines of Lockyer's celestial helium. So, for the first time, an element was discovered in the heavens and then found later upon earth.

The next triumph was the joint discovery by Ramsay and Soddy that when radium is undergoing spontaneous disintegration, the alpha particles are nothing more than charged helium which had previously formed a portion of elemental radium.

In the present year Ramsay and Collie have shown that helium, along with another gas of the argon group, called neon, appears after long continued action of X-ray bulbs, and accumulates in the glass of the bulbs where the radio-active matter strikes the glass. The glass at such places also turns a beautiful

purple, due, it has been supposed, to potassium liberated in the glass from the chemical-disintegration of the material of the glass caused by the electronic bombardment.

It is a well-known fact to all radiographers that X-ray bulbs undergo slow changes in their qualities on account of changes in the nature of the vacuum within the bulb. This subject demands more investigation than it has hitherto received. The common view at the present time is that helium and the electrons (or alpha and beta particles) produced in X-ray bulbs are detached from the material of the negative electrode, but proof of this is lacking, and it may well be that the electric energy really synthesizes these first forms of matter from the luminiferous ether which fills the bulb. A strong point against the origin of helium and electrons being from disintegration of more highly synthesized material of bulb or electrodes is that the electrons are invariably the same whatever the material of the electrodes, while the disintegration products of varying chemical molecules or atoms should show great variations, as, for example, a pulverized rock would show the nature of its origin in the minute particles. Also the number of exactly similar electrons is enormous compared to the yield of rare

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gases. Now, theoretically, electrons must be identical whatever their origin, and so, if the source were disintegration, there ought to be much of the intermediate products, such as helium, xenon, neon, argon, and hydrogen, and little of the single constituents or ultimate fragments. But if the source were synthesis from the ether, it might be suspected that there would be much of the first stage of synthesis or electrons, and fewer of the more complex products or rare gases. The second is what is found experimentally, but it may well be that in any such active electrical discharge both synthesis and disintegration of matter go on alongside of each other, and that a study of experimental conditions will allow us in the future to cause whichever we choose to predominate.

It has been said above that the spectra of different stars show important differences, and this not only gives a guide to a classification of the stars according to their temperature but yields important evidence in regard to evolution at the inorganic stage. The evidence is that the same element is in different conditions at different temperatures, and also that at lower temperatures certain elements exist which disappear at higher temperatures, and are replaced by others, these

latter elements being absent at the lower temperatures.

In studying this subject the same element, such, for example, as iron, may be experimented upon at different temperatures, and when this is done, remarkable changes are seen as higher temperatures are reached. In the flame of the spirit-lamp or a Bunsen burner, the lines of sodium, as has been said above, are easily produced, but a metal like iron shows nothing. In the blow-pipe flame, the iron shows the dawning of a spectrum by giving series of bands or flutings, a "fluted spectrum," as it has been termed. When the energy of the voltaic arc has been reached by sending a strong current, such as is used by electric tramcars or for lighting, between poles made of iron, then a line spectrum is first reached for iron, and this shows thousands of lines specific for iron at such a temperature. Flame arcs yielding light which would give such spectra are often seen between wheel and rail of a tramcar when vibration of the car or some dirt upon the rails has temporarily broken contact, and an iron arc is formed. A similar copper arc is also frequently seen above when the trolley-wheel leaves the overhead conducting wire, and for a moment a copper arc is established. The now well-known

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green light of the mercury arc lamp is another example of a metallic arc which would give the mercury spectrum. The spectrum given by the electric potential of the ordinary voltaic arc and produced at the high temperature of this electric furnace, is not, however, the last word as to what can be done in the way of temporary disintegration of the more permanent metallic elements into what have been termed by Lockyer, proto-metals.

Other forms of energy at a high pressure or potential seem to possess a power of causing atomic disintegration which heat alone does not possess, for the electric pressure in the ordinary arc-flame in air is so low comparatively, that the chemical effects here must be ascribed almost solely to the great heat produced in the crater of the arc by the conversion of large quantities of electrical energy at low pressure into heat. This operation is like using the energy of a large river of water falling only a small height.

When, instead of the ordinary air-arc, recourse is had to an arc in a high vacuum spark-gap several inches in length across which high tension electricity at an enormous pressure of some hundreds of thousands of volts is made to leap, then a new set of phenomena at once make their appearance, and the

spectra in the case of most metals become entirely changed, showing that a new stage in the disintegration of the metal has been reached. For example, the iron arc-spectrum of the voltaic arc contains some thousands of lines, as if the iron atom might be regarded almost as a planet which by the agency of the intense heat of the arc had been split into thousands of meteorites. But at the conditions of the vacuum spark spectrum, these thousands of lines have disappeared, and become replaced by a few much more strongly marked lines, three of which are especially characteristic. These lines, from their strength and their persistence in greater intensity when the others have disappeared, are called the "enhanced" lines of iron. Now, apart altogether from stellar spectroscopy, this series of changes in the lines of a metallic spectrum most strongly indicates, if indeed it does not prove, a corresponding change in the elemental constitution of the metal while under the energy-environment of the air-arc or spark-gap respectively, and it will presently be seen that under energy conditions which we cannot at present attain upon earth, even the spark-spectrum of certain metals disappears at certain levels, showing still more complete disruption. The many-lined arc spectrum

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of iron would appear to indicate a position with many unstable intermediate disruption products of iron, which passes on by the break-up of these into the small number of stable products (under the given energy-environment) represented by the small number of enhanced lines of the vacuum spark spectrum.

The next step in the chain of evidence of the evolution of the elements is that when the spectroscope is turned toward the sun there most clearly seen are the important enhanced iron lines of the vacuum-spark spectrum, and no trace of the multitudinous lines of the iron air-arc spectrum is to be seen. What conclusion can be drawn save that iron exists not merely as vapour in the sun, but as vapour elementally decomposed to the stage at which it is found in a vacuum spark-break spanned by an electrical tension of a hundred thousand volts?

There exists at present no form of thermometry which will enable us to determine whether the temperature in the actual spark region is an enormous one, or whether the transformations there shown by the spectroscope are directly electrical ones. Certainly the bulb as a whole does not require a high temperature. This point is an important one

because there are many nebulae in which the spectroscopic findings would indicate a very high temperature, yet other things do not favour such a view, and it may well be that in such regions electrical charges causing transformations of energy at high potentials are the causes at work. Also, in the case of our sun, there may be other forms than heat energy at work giving the spectroscopic results.

If these results of enhanced spectral lines as observable in the solar spectrum, however, be taken as due to temperature alone, then the solar temperature far exceeds that of the electric arc which gives the highest temperature of matter *en masse* known to us terrestrially.

As has been stated above, the temperature of the high tension vacuum spark cannot be measured, so meanwhile it must be left as an open question. Experimentally the effect that has been obtained by passing from the low-tension air-arc to the high-tension arc, may be expressed from the standpoint of energetics by saying that in the former case a *large* amount of matter has been heated to a high temperature, in which it volatilizes at considerable pressure, while in the latter case by concentration of much energy at high

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pressure on an infinitesimally *small* amount of matter (a quite unweighable amount of matter), this has been volatilized at a very low pressure in a vacuum, and so loaded with energy that it disintegrates.

It is the proof of disintegration that interests us here because that is only the reverse of synthesis, and we are studying how these forms of matter can originate by observing how they may be pulled apart, and what happens then.

To any person unloaded mentally with early training as to the inviolability of the chemical elements and the sacredness of the conservation of the elements, the changes above mentioned in the spectra would form strong presumptive evidence of the composite nature of iron, and similar proof exists in the case of other elements. But stellar spectroscopy possesses additional experimental evidence which raises the presumption almost to a demonstration.

It has been pointed out above that a slight deflection to right or left of a well-known line proved that the material giving origin to that line was moving towards or away from the spectroscope, so raising or lowering the colour-tone or pitch of the light causing the line. Now in sun-spot observation, this

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remarkable thing has been seen; one of the enhanced lines of iron is stationary, while the other two indicate motion. This amounts to a proof, not merely that the proto-elements of iron exist apart in the sun's atmosphere as they do side by side in the vacuum spark on earth, but that immense translational velocities are actually separating them from one another. This arises because one is more stable at one zone of solar energy conditions, and the others at other zones. Apart from iron, this has been shown by taking sectional or zonal spectra of the corona or sun's margin, in solar eclipses, and so sampling the sun's atmosphere at various levels above the central portion. While there are enormous surgings up and down the spectra show predominance of different types of matter at different levels, and these indicate different temperatures (or other energy-distributions) similar to those observable in many different suns, and upon which these stars have been classified spectroscopically as shown below.

In the sun, and incandescent stars and nebulae, there is not merely the momentary separation by the disruptive electric discharge such as can be produced terrestrially, but a permanent condition of disruption over a large field, as a result of which the constituents,

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or proto-elements, can separate from one another, or diffuse out as the chemist terms it.

The next experimental stage required terrestrially is some mechanism to separate the proto-elements while the sparking is in progress in the vacuum tube. If a magnetic or electric field could be utilized to deflect one constituent in one direction and the other in the opposite, as can be done at present with the alpha and beta particles, a whole series of brilliant advances would be made.

There is little doubt that in time this advance will come and that the chemistry of the future will realize the dream of the alchemist and succeed in transmuting one element into another. Electrical energy will, in all probability, take on the rôle of the philosopher's stone, though at first artificial gold, as artificial diamonds are nowadays, may be more expensive than natural gold.

The glut of gold does not, however, dim the vision of the modern thinker; he sees higher and more glorious things than this, and is more concerned with matter and energy at more primeval stages, with the history of worlds in the making, with the splendid continuity of nature, and the entrancing romance of how life came upon earth, and

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step by step went onward, creating the beautiful, and, more wonderful still, introducing that intelligence which can admire beauty, and can worship, not with ignorant obeisance, but in skilful and participating science or knowledge.

These primeval beginnings of the transmutations of matter and energy, with the formation of the proto-elements and elements, are illustrated by the present stages of the developments of worlds, as seen by the astronomer, in the constellations of all ages which surround this world of ours.

Armed with the telescope and spectroscope, we stand, as it were, in an immense cosmic picture gallery, in which instead of each picture being finished, in many cases hundreds of years ago, each picture is unfinished, and the artist is at work upon it. Just as in a national gallery there may be studied the history and evolution of art in the past, so to-day in the heavens and upon earth there can be studied the problem of the evolution of nature's architecture of matter. What a wonderful revelation to the historian and artist it would be, if instead of dead records and finished works executed in the past by creative acts consummated once for all and never to be repeated, the living happenings were before

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his eyes. If he could stand in a modern gallery and see artists of all ages and generations at work, or talk to writers, dramatists, and philosophers of all times. Yet this is what the scientist possesses in living intensely active nature, and this glorious thing it is that he is sometimes asked blindly to surrender for a pre-conceived unnatural world with isolated creative acts ended in the distant ages of the past, never repeated now, and of which the key has been for ever lost.

Truly we are only beginning to realize as in a dream that creation and the design of creation is something nobler than man's intelligence has yet conceived, that Nature is not powerless to create again such as she has once created and is still at work, and that we must look with fresh eyes and fresh interest at things being produced with eternal youth from the womb of Nature.

Continuity, not dis-continuity, is Nature's plan, and it is only by centring thought around our own individual lives, whose relationships and pasts and futures we do not understand that preference arises for dis-continuity. The full and true relationships of the individual life will only become realizable by patient study of the whole cosmical scheme.

The stellar evidences of the synthesis of matter and the creation of worlds, leaves the position entirely untenable, that life once came by a single creative unrelated act upon this earth, or any other earth from which it was carried to ours. Life is at present originating in countless other worlds as daily it is originating upon our own, and given a certain stage in evolution when matter has reached a certain complexity in structure, and become tenanted by certain types of energy, life must come, and having come must evolve into higher and higher forms.

The first stage of all is the evolution from imponderable proto-matter, or ether, of the electron, from the electron arise the proto-elements, and from these the inert gases of the helium group and hydrogen, and by various unions of the proto-elements, the elements as we know them at terrestrial temperatures and conditions, arise.

It is an observation of the highest interest in the stellar evolution of the elements, as has been pointed out by Lockyer, that it is in the hottest stars that the simplest forms of matter are present, and that the incandescent bodies of the heavens can be classified on this basis.

The following is the classification pro-

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visionally submitted by Lockyer in his book on "Inorganic Evolution."

CLASSIFICATION OF STARS :

| | | |
|-------------------------------|----------------------|--|
| <i>Highest temperature.</i> | | |
| a. Gaseous Stars | Proto-hydrogen stars | { Argonian Alnitamian. |
| | Helium-gas stars | { Crucian Acherian Taurian Algolian |
| b. Proto-metallic Stars | Rigelian | Markabian |
| | Cygnian | — |
| | — | Sirian. |
| c. Metallic Stars | Polarian | Procyonian |
| | Aldebarian | Arcturian. |
| d. Stars with Fluted Spectra. | Antarian | Piscian. |

Lowest Temperature.

As to the terminology used in the above table the termination "ian" is used to indicate an epoch or stage in the process of evolution much as the same termination is used in geological evolution for the termination of a primary division of strata as in the words "Devonian" and "Silurian." As the processes are here simultaneous in different worlds, instead of chronological in order in one world, temperature takes the place of time, but the same effects would happen chronologically could the process be observed in the same sun over a period of millions

of years. The order of evolution of the elements would thus happen in the same fashion as the origin of organic species in the geological epochs. In geology the range of temperature is infinitely shorter, and the gradient of fall of temperature slower, so that some millions of years witness but the fall of a few degrees in temperature.

The names for the stellar epochs are derived either from that of a typical bright star which possesses at the present time a temperature indicated by its spectrum, or sometimes the name of the constellation in which the star is found. Where two columns of names of stars are given those in the first column are stars of which the temperature is at present supposed to be increasing, and where evolution would be reversed or in the direction of disintegration. The second column contains stars with decreasing temperatures, where elemental evolution towards higher atomic weights is progressing. Our own sun would be placed in this column at the level denoted by Arcturian.

The word proto-hydrogen in the table indicates that in these hottest of all observed suns (two suns in the constellation Argo), a series of lines are met with belonging to no known terrestrial element, but standing in

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relationship to known hydrogen lines, and supposed to be precursors of that element. The other predominant lines at this level of stellar temperature and evolution, are those of hydrogen as seen terrestrially when hydrogen is sparked with an electric coil in a vacuum tube. Much fainter lines are seen of helium, proto-magnesium, and proto-calcium. No lines of iron are visible here, even in the proto-form. Next come stars of the helium group, where the spectrum of that gas is prominent, associated still with hydrogen, and the spectral lines of proto-carbon, oxygen, and nitrogen are now clearly present.

In the proto-metallic stars, the precursors of such metals as iron, copper, manganese, nickel, titanium, and calcium, make their prominent appearance.

When the metallic spectra are reached such lines as distinguish calcium, iron, and manganese in the ordinary voltaic air-arc are present, while many of the proto-lines become dimmer and disappear. Lastly, the fluted spectra appear, of carbon or manganese, with fainter metallic lines.

It is thus seen that the more primordial constituents of matter are those formed in the hottest stars, and that as temperature falls the ordinary elements become synthesized.

The evidence of the heavens corroborates that given by terrestrial disruption by high tension electricity in a vacuum, by the evidence of the X-ray bulb, and by that of the radio-active disintegration of the atoms possessing high atomic weight.

The whole tale of elemental evolution holds together, is consistent, and leads to new discoveries. This is the distance which stellar observation and the study of radio-active matter take us on our journey; from this point the way lies amidst ordinary chemical combinations of the elements amongst one another to form molecular combinations or chemical compounds. There is no breach of continuity as we enter this zone, the same laws of interaction hold, but greater specific differences in the forms of matter arise; there is more chemical individuality, and there are new conditions of energy manifestation.

Thus, such a well-known substance as water, as the temperature is elevated, would break up into the two elements, hydrogen and oxygen, which compose it, long before such a temperature as that of the coolest of the stars mentioned above had been reached. There exists a temperature, however, at which a mixture of steam (or gaseous water) can exist alongside of its two constituent gases,

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and at a lower point still these two gases unite together firmly with great discharge of energy. Lower still the gaseous water condenses into liquid form. What happens for water happens for thousands of other combinations of the chemical elements which are known as chemical compounds. Each compound contains a definite number of atoms of each of two or more chemical elements.

The simplest of the compounds, and those first formed in complexity, are the so-called *binary* compounds which contain only two elements present in such amounts as correspond to some simple atomic relationship. For example, water consists of two atoms of hydrogen and one atom of oxygen, and common salt consists of one atom of a metallic substance called sodium, united to one atom of a gas called chlorine, so that it possesses the chemical name of chloride of sodium.

In order to understand something of this stage in evolution it becomes necessary to explain two specific or individualized properties which here begin clearly to differentiate the various forms of matter, and are called chemical *affinity* and chemical *valency*. This is the first definite inorganic dawning of that

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high specialization or adaptation which is seen with exquisite refinement and balance in living organisms.

CHAPTER IV

CHEMICAL COMPOUNDS ON EARTH

AFTER the various forms of the atoms have been forged in the mighty furnaces of the suns, the differences in atomic structure so imparted to them cause them to possess specific dynamic properties varying from one sort of atom to another. It is not to be supposed that the constituent groups of electrons forming an atom are at rest and fixed; but rather that each possesses the properties of an infinitely small microcosmic system with constituent groups of electrons in vibrational or orbital movement in respect to one another. The atom is in reality characterized by the amount of energy it contains, and is not to be looked upon as a dead mass with fixed motionless structure. It is necessary to insist upon this because the chemical symbols by which the chemist attempts to fix and visualize the atoms with

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which he is dealing produce a stereotyping effect on the mind, and unless the student is always on the alert, he is apt to come to believe that the atom is what the symbol represents it to be, a fixed or motionless structure, whereas it is in reality a centre of ever-moving energy. It is by virtue of its dynamical power that it undergoes chemical transformations with building up or breaking down of chemical compounds.

Within the limits of ordinary chemical reaction no changes of sufficient violence occur to invade the energy equilibrium of the constituent groups of electrons constituting the atoms, so the atom may be regarded as stable, indestructible, and indivisible in the sense explained in the previous chapter.

The atom may accordingly be accepted by the chemist as a working unit just as the biologist still accepts the living constituent cell of the plant or animal as a biological unit, and the facts of the preceding chapter need no more invalidate this position, than the corresponding fact in quite modern biology that many of the properties of the cell may be carried on by isolated parts of the cell, which a few years ago were only considered possible for the entire and undivided cell to perform.

Each one of the chemical atoms possesses a different weight, which is utilized as an indicator of the amount of matter in it. Until quite recently the absolute masses of the atoms were unknown to us, it is one of the many triumphs of the study of radio-activity that we now know them, but for ordinary chemical operations it is only necessary to know their *relative* weights and these relative weights are what are known as the atomic weights of the elements.

When two or more elements unite to form a chemical compound, the masses taking part in the reaction are always so related that they may be expressed as simple multiples of the atomic weights. This shows that always a definite number of atoms enter into the formation of each compound, and it is for this reason that under similar conditions of environment, all the characters of a chemical compound are absolutely definite and invariable. Thus two atoms of hydrogen always combine with one atom of oxygen to form what is termed a molecule of water, and never in any other ratio or proportion is water formed. Thus one molecule of water is always precisely similar to another molecule, and, hence, in the mass, or bulk, if water be quite unmixed with anything else, one sample

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of water is the same in all its qualities as another sample. Two atoms of hydrogen unite with one of oxygen to form water, but if hydrogen and the yellowish gas with bleaching properties called chlorine happen to be the two kinds of atom uniting, then it is found that *one* atom of hydrogen and *one* atom of chlorine unite, and the product of their union is called hydrochloric acid.

In another case, when *one* atom of an element called nitrogen, which forms the predominant component of the atmosphere, unites with *three* atoms of hydrogen, there is formed the molecule of the gaseous body which we term ammonia. Again, if *one* atom of the solid element carbon unites with *four* atoms of hydrogen there is formed a gas known as marsh gas, or methane. As a final example, there may be mentioned the liquid substance, chloroform, of which one molecule is formed by the union of *one* atom of carbon, with *one* atom of hydrogen, and *three* atoms of the above-mentioned gas, chlorine. These particular examples have been chosen in illustration, for a special purpose which will become obvious presently. The points to be observed at present are two, namely, that there is always a definite number of atoms of each kind of constituent element, and secondly

that sometimes the atoms unite in the ratio of one to one, at other times two to one, or three to one, or even as in the case of carbon and hydrogen, four to one.

As there are eighty or more forms of elemental matter, and as there may be from two to as many as six or seven different elements, and these in different arrangement and numbers of atoms, in the compounds, it follows that the number of chemical compounds is legion. For out of twenty-six letters in the alphabet any number of words may be formed, and three or four words on the back of an envelope will take a letter safely to one of many million individuals. And, as the individuals are arranged in countries and communities and families, so also the groups of chemical compounds are related and organised and arranged, and a great part of the science of chemistry consists of the study of their organisations and relationships.

Space forbids us entering into details of such study, it will be sufficient for our present purpose to point out that these elements unite with one another with very varying degrees of intensity, or as the chemist expresses it, possess varying chemical *affinities* for one another, and, secondly, that in uniting they possess different *valencies*, or chemical

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values, for satisfying or saturating one another. These two properties of affinity and valency lead to formation of the chemical compound, or single chemical molecule, which carries us the next step forward in the process of evolution leading towards life.

The varying degrees of affinity may be illustrated everywhere in chemistry with the greatest ease, our own lives depend upon such varying affinities at every moment, and chemical affinity is seen daily in varying degree in all the familiar objects around us. But perhaps the best example to place before the non-chemist is that seen in the rusting or oxidation of metals. It is well known that gold remains bright in the air, while silver slowly tarnishes, lead tarnishes quite rapidly, copper turns green, and iron coats itself with a red rust. These metals are all elements, and their rusting or tarnishing is due to their surface layer uniting with the oxygen of the air to form chemical compounds known as oxides. The familiar occurrences mentioned above illustrate varying degrees of chemical affinity. Now, by methods which need not be described here, the chemist can measure the amount of energy set free or absorbed when elements unite, and so obtains measures for the chemical affinity. As a result

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enormous variations are found, and when a number of various claimants for chemical union are present, as for example, in a world cooling down in space, the varying amounts of different chemical compounds formed and their variety will depend on the amounts and affinities of the constituents present.

In these questions of affinity two factors come in, there is always an affinity to be overcome, as well as the one which is satisfied as the result of the chemical action between the two substances or elements. It is rarely that the atoms of an element exist singly in nature. When such elemental atoms cannot find other dissimilar atoms to unite with they unite with each other, usually in pairs. These pairs must be sundered on both sides before union of the two different kinds of element can take place. For example, it is not really two atoms of hydrogen and one atom of oxygen that unite to form a molecule of water. But two *molecules* of hydrogen, each containing two atoms of that element, and one molecule of oxygen, likewise containing two atoms of oxygen, have to be severed first, and then, when freedom has been obtained, each atom of oxygen becomes attached to two atoms of hydrogen, so that

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two separate molecules of water are formed. This is the way the matter must be put to render it readily understandable. As a matter of fact, for any such chemical reaction, thousands of millions of molecules of hydrogen and oxygen are ruptured simultaneously, but the above statement represents the proportions in which the molecules are concerned.

The second main characteristic of valency is also illustrated in the above example. It is to be noticed that two atoms of hydrogen are required to each atom of oxygen. The atom of oxygen has double the valency of the atom of hydrogen, in this reaction. In the formation of ammonia, as union of one atom of nitrogen with three of hydrogen occurs, the nitrogen atom has treble the value of the hydrogen atom, and, in the other example given above of marsh gas, the carbon atom possesses four times the valency of hydrogen.

A number of elements exist which possess the same valency as hydrogen, such as chlorine mentioned above, which unites atom for atom with hydrogen to form hydrochloric acid, and the same is true of the other members of the chlorine family, namely, fluorine, bromine and iodine, which similarly unite atom for atom with hydrogen to form

hydrofluoric, hydrobromic and hydriodic acids respectively.

Proceeding on the axiomatic basis that things which are equal to the same are equal to one another, if it is found that other elements unite with chlorine, one to one, such, for example, as the alkali metals, lithium, sodium and potassium, which form lithium chloride, sodium chloride, and potassium chloride respectively, then it is possible to say that the valency of these three metals is the same as that of hydrogen. It is necessary to follow this deductive step closely, for much depends on it. The argument is that two atoms, viz., one of hydrogen and one of chlorine, unite to form a compound containing one atom of each, their valencies are accordingly equal, now hydrogen (the measure of valency) cannot be united with lithium, sodium and potassium, since it possesses practically no affinity, or chemical avidity, for them, but chlorine unites with the atoms of these elements in the ratio of equality to form molecules known as chlorides, which possess one atom each of chlorine and of one of these elements. The inference is that lithium, sodium, and potassium are equal in valency with hydrogen and chlorine. Experimentation on this basis

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completes gradually the list of elements all equal to hydrogen and to one another in valency, and as no elements in nature are found of a lower order of valency, such, for example, as would unite two of their atoms to one of hydrogen or any others of the above group, it becomes obvious that the valency possessed by hydrogen, and its equals, is the minimal valency. These elements are accordingly called monads, or univalent elements.

The next order of valency amongst the elements is such that an element belonging to this group possesses double the affinity of the monad, and these elements are called dyads or divalent elements. This is a large group of which oxygen may be taken as the type. As stated above, water shows the divalent nature of oxygen, for one atom of oxygen is united in it to two atoms of hydrogen. The same runs through all the oxides of the univalent metals mentioned above for two of each of these unite with one of oxygen, when they combine spontaneously with oxygen to form oxides. Compounds are also known in which, instead of two atoms of each alkali metal, one atom of the univalent metal and one of hydrogen unite with the divalent oxygen to form compounds called

hydrates, which are thus compounds containing three elements. For example, that well-known substance called sodium hydrate, chemically, or caustic soda, commercially, of which our country manufactures millions of tons annually for soap-making and many hundreds of industrial uses, is very simply composed of an atom of divalent oxygen united to one atom each of univalent sodium and univalent hydrogen. It might be regarded as water with one of the two hydrogen atoms replaced by the metal sodium, which possesses a stronger affinity for the position. It is for this reason that caustic soda is called a hydrate, and it may be actually made by throwing a small piece of metallic sodium on water when the water is decomposed, hydrogen discharged, and set fire to by the heat energy evolved. This hydrogen burns with the oxygen, re-forming water, and the sodium present colours the flame that intense yellow, which gives the sodium spectrum referred to in the previous chapter.

Just in the same way as hydrogen was used for measuring out the univalent group, the oxygen atom may be used for measuring out the divalent group. For example, the metals calcium and copper each unite atom

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for atom with oxygen to form compounds containing only two atoms, and this leads the chemist to suspect that these must be divalent elements. Now, on forming compounds of these with chlorine the suspicion is confirmed, for each unites with the chlorine under ordinary conditions to form compounds in which two atoms of chlorine are united with one of the calcium or copper. . In the same way elements which act as triads, tetrads, pentads, and even hexads can be identified.

In chemical interchanges and variations from compound to compound, it may generally be said that where chemical affinities permit of it, one monad can replace another, or a dyad atom may be replaced by two of a monad, or by one atom each of two different monads, and so on ; but circumstances often arise which make this rule inapplicable. For example, where a dyad is acting as a connecting link between two groups of atoms it cannot be replaced by two monads without the compound splitting into two smaller compounds to each of which one of the monads attaches itself.

Another complication arises because of the tendency possessed by elements with higher valencies to lower their apparent

valency by a kind of internal union of certain of their valencies, much in the same way as it was pointed out above that two atoms of hydrogen unite to satisfy each other in the absence of more powerful attractions of other elements. For example, nitrogen and phosphorus are pentavalent atoms which possess five dynamic centres of energy capable of forming combinations. But in the majority of their compounds, two of these dynamic centres set up internal attractions or perturbations in regard to each other, as a result of this the nitrogen or phosphorus is left with three free dynamic centres, and possesses an apparent valency of a trivalent element. A similar effect is often seen between two atoms of a polyvalent element. For example, two carbon atoms may come into energy relationship by two of their dynamic centres or valencies and, as a result, although each carbon atom possesses four valent positions, the two atoms after this union of themselves have only two centres left upon each atom, or four in all, and a compound is formed of two atoms of carbon with four of hydrogen, the well-known olefiant gas.

In settling valencies, the greatest caution has accordingly to be observed by the chemist.

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He deals, if possible, especially in studying the elements with higher valencies, only with compounds of simple type containing if possible only one atom in the molecule of the polyvalent element, and he directs his attention to the compound which he can prepare with the highest valency exhibited, and in that compound univalent elements so far as possible occupying the available dynamic centres of the polyvalent element. In his quest he is assisted by many experimental touchstones which need not here be considered in detail.

Carbon is that one of all the elements that concerns us most intimately because its high valency and its unparalleled power of uniting with itself as well as with other elements, enables it to build up single molecules containing very large numbers of atoms, and such molecules form the basis for framing the structure of living organisms. Without these two properties of the carbon atom, life, at least as it is known upon the earth, would be impossible, and accordingly it may be well to describe in outline, as simply as possible, the proof that carbon is a tetrad element, and the results in molecule building which rest ultimately upon its remarkable power of self-union.

It has been said above that two carbon atoms can unite and so partially saturate each other, and leave over four positions which can be occupied by four hydrogen atoms so giving a compound of two carbon and four hydrogen atoms. But how, it may be asked, is it known that this compound does not consist of one carbon atom and two hydrogen atoms, the relative proportion of carbon and hydrogen would be just the same, and then carbon would be a dyad, since it unites with two hydrogen atoms? The proof lies in the weight of the gas formed relatively to that of hydrogen, when equal volumes are weighed. All gases contain in equal volumes, under like conditions, the same number of molecules, as is proven by many concordant facts in physics and chemistry. This gives a criterion, for it is obvious that, if in one case the gas molecule contained one atom of carbon and two of hydrogen and in the other, two atoms of carbon and four of hydrogen (since the weight of the volume of gas is the united weight of all the molecules), then in the second case the gas must be twice as heavy as the first. The latter result is the one found experimentally, the density, or weight per equal volume, of the gas compared to hydrogen shows that its molecule must

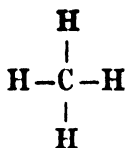
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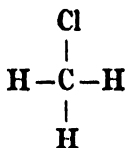
be made up of two atoms of carbon and four of hydrogen. So such an apparent exception is accounted for, as can all similar cases.

Coming now to direct evidence as to the tetra-valent nature of the carbon atom, it is found that the clearest proof is given by a series of compounds between carbon, hydrogen and chlorine, in which there exists only one atom of carbon in the molecule of each compound, and the hydrogen can be replaced in *four* stages by the chlorine in such a way that it is demonstrated that there are four atoms of hydrogen in the compound which has most hydrogen and four atoms of chlorine in that which has most chlorine.

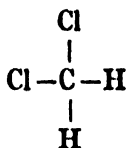
The compounds can be represented by the following scheme, but it must most carefully be remembered that the atoms are not really linked or hooked together, but probably many hundreds of times their own dimensions removed from one another. It is the energy properties of the carbon atom which in some unknown way enable it to remain in balanced equipoise with four of these univalent atoms, and never with more or less than four of them. In the formulæ, or symbols, C stands for carbon, H for hydrogen, and Cl for chlorine :—



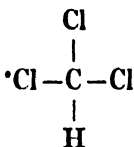
(1)



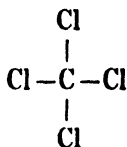
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(3)



(4)



(5)

All the members of this series are well-known bodies. The first is called chemically methane, or from its natural occurrence, marsh gas. The second is called methyl chloride, the group (CH_3) united to the single atom of chlorine forming a characteristic group in organic chemistry which goes into and comes out of compounds as if it were a single univalent atom; such a group is called an organic radical. The third member with two chlorine atoms is called di-chlor-methane, for obvious reasons. The fourth member with three chlorine atoms is the well-known anæsthetic, chloroform; its chemical name is tri-chlor-methane. The fifth member where all the hydrogen has been

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replaced by chlorine is called carbon-tetrachloride, and is an exceedingly valuable organic solvent, especially for bodies of a fatty nature. It has the desirable property that it is not very readily inflammable, as ether, benzene, and many other organic solvents are. •

All these bodies are formed in varying quantities when the two gases methane and chlorine act upon one another, and by appropriate means can be separated and identified. Once this has been achieved, large quantities can be manufactured by more appropriate methods, and their chemical nature examined. The densities of their vapours compared with hydrogen show that only one carbon atom is present, and when they are burnt or combusted with oxygen, and the percentages of carbon, hydrogen, and chlorine estimated by analysis, the numbers of atoms present in each case can be calculated, on the basis of the known atomic weights of the elements as settled by the concordant analyses of many other simple inorganic compounds. When this has been done the only formulæ which will fit the compounds are those set out above.

It follows from this that the carbon atom is a collection of energy forms, or electrons, possessing such dynamic properties that it

is in equilibrium with four univalent atoms or their equivalents. Such equivalents may be legion, and so long as the carbon atom has four centres of activity satisfied by four such centres outside itself, it is saturated and in equilibrium. Failing outside attractions two of the four may enter into interplay with each other, and such a carbon atom is then spoken of as an *unsaturated* carbon atom. The name is in reality a misnomer, for it is saturated, except when something of superior affinity presents itself, and then the two dynamic centres which were previously playing upon each other, enter into relationship with the new body. For example, the compound called carbon-monoxide which forms the poisonous constituent of coal gas, or in the gas from a charcoal fire, or brick-kiln or lime-kiln, is such an unsaturated compound with one tetrad atom of carbon united to the dyad atom of oxygen, and the other two affinities of the carbon atom more feebly satisfying each other by self interplay of energy. If now, this gas be mixed with chlorine gas the chlorine interacts spontaneously with the two carbon affinities which were previously interacting with each other, and each of these now comes into dynamic interplay with a chlorine atom. As a result,

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there is formed the substance called carbonyl chloride, of which the molecule contains one carbon atom, one oxygen atom, and two chlorine atoms. If, more simply, the carbon monoxide is burnt in the air, one extra atom of oxygen enters into relationship to the two affinities of the carbon, and the very common substance carbon-dioxide is formed. This body is present in minute amounts in the air, and it is of interest to note here that from it the green plant is able when it is aided by the energy of the sunlight, to build up those organic substances of complex nature found in living plants.

It is a curious fact that all life on the earth should depend upon two simple factors, (1) the presence of a mere trace, lying at the level of only between three and four parts per 10,000, of this gas in the air, and (2) the natural power of the carbon atom contained in the carbon-dioxide, of entering into energy relationships with fellow carbon atoms. Given these conditions, a suitable form of energy, and a suitable machine or transformer for that energy capable of turning it into chemical energy of carbon compounds, and it follows that all the complex organic constituents which form the basis of life not only can, but must arise

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The energy-transformer is the green plant-cell aided by the green colouring matter, called chlorophyll, which it contains. The energy which is converted into chemical energy of organic compounds is that of the sunlight, and the simple forms of matter which undergo transformation, are the carbon-dioxide above mentioned, water, and simple inorganic salts containing compounds of nitrogen such as ammonia or nitric acid, and a few common elements of inorganic nature as simple salts taken up from the soil. In this natural laboratory of the plant, energy is introduced into these simple forms, their chemical constitution is thereby changed, and they become storehouses of energy in chemical form. These organic forms of matter, so elaborated, form the food of animals by whose activities they are finally broken down into their original forms, or others closely resembling them, and so the cycle is completed. All energy of all living things is dependent upon green plants, and they in turn are dependent upon the sunlight.

As will be pointed out later, all commencements of life now or earlier must have depended on sunlight, but it is highly improbable that the exceedingly complex green cell of the plant formed the starting point. Life

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had to surge a long way up from the depths before a green plant cell came into being. Once such a cell was formed it would retain its stability under suitable environment, and form a new point of departure, but there exists a wide hiatus between inorganic molecules and the green plant cell which we must bridge as best we may before we begin to understand the origin of life.

The present is, however, the place to describe briefly that peculiar property possessed by the carbon atom of uniting with its fellow atoms, which is there ready to yield material for the physico-chemical structures of life so soon as the energy transformer has been evolved. In later chapters, the interval will be dealt with lying between inorganic molecules and the green plant cell and its organic products.

It is only a chemical atom possessing a high valency which is capable of uniting in this way so as to form a very large molecule, apart from the quite different mode of formation of bodies called *colloids* to be dealt with in the next chapter. Colloids, it will be found, are formed by molecular unions in which each molecule behaves as a single atom, just as previously in forming the atoms the electrons united. In the colloid, each constituent

molecule of an aggregate of molecules, is completely saturated, and there is no *atomic* affinity between the molecules. This is entirely different from the point being described here of the building up of a giant single molecule by the aid of the carbon atom. For this latter purpose, the central or building atom must have a high valency, and yet the valency must not exceed a certain limit. Univalent atoms obviously cannot build up a large molecule by themselves, because when two unite no more atomic affinities are left over. The only apparent exceptions are where such a binary compound of two univalent atoms unites with water to form crystals, or where two such binary compounds unite together in a feeble way. But this is not atomic union at all. It belongs to the molecular combinations described in the next chapter.

If we next consider a divalent element attempting to unite atomically to form large groups, it becomes obvious that to form any dynamic concatenation, or constellation, each atom will have to unite with two others, and hence no affinities are left over to enter into similar relations with the other dissimilar elements necessary to make up the molecule. For example, a large number of oxygen atoms might begin to bind together in interplay,

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but both affinities would be involved in holding them in such relations, and so none would be left over for attaching any other element. Hence the whole group could be oxygen, and oxygen only ; no compound could be formed.

The lowest valency at which such dynamic grouping of a considerable number of atoms could occur is that of the trivalent atom, where after the unions of the trivalent atoms one valency would be left upon each for union with the dissimilar atoms or groups. Although this is feasible there are objections from the point of view of stability of the system, for while in process of building up in the tetrad grouping there are two affinities left over on each atom which can interplay with each other and hold each other balanced in equilibrium, until other atoms or atomic groups of a dissimilar character present themselves ; in the case of the triad, only one unbalanced activity, or valency, is left over on each atom, and this is an exceedingly unstable situation, so that the system breaks up. Also it is questionable whether true trivalent atoms exist at all in nature because they are themselves so unstable. The elements of the phosphorus group, namely, nitrogen, phosphorus, arsenic, and antimony, which

appear to be triads, are really pentads which have become facultative triads by self-saturation of two of the active centres. If such elements united to form a large group, as the element carbon does, there would be this additional element of instability, in that every member of the group was unsaturated, in addition to the union of the similar elements to one another. It is thus seen that the elements of which the valency is represented by odd numbers are not suited for taking on central rôles in large groupings of atoms into a single giant molecule.

When the valency of a hexad is reached, as has been claimed to be the case in the iron group, the atom itself reaches nearly the limit of internal stability, and is just able, in single or dual atomic groupings, to unite with other dissimilar atoms, but any higher interaction between the similar hexad atoms than two joined together is never found. It is indeed a matter of doubt whether hexad elements exist. The energetics of such forms of atomic matter at the present state of our knowledge are but little known, and the valency theory gets into difficulties in explaining them. It becomes clear, therefore, by such processes of exclusion that the type of element in which the electrons are so arranged

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and balanced, that the atom possesses the power of balancing in stable equilibrium with four monad atoms or their equivalent, is that form alone which can build up huge mono-molecules.

This is what is found actually to occur in nature. Carbon, which is the most typical tetrad, shows the property in highest degree, the only other element approaching near to it being silicon, which is also a tetrad.

CHAPTER V

BUILDING MATERIALS FOR LIVING MATTER

As a result of this wonderful property of self-equilibration of dynamic properties in the carbon atom single molecules are capable of forming, which contain some hundreds of carbon atoms, and often in the life processes such molecules are built up with molecular weights running into several thousands, while inorganic mono-molecules only run into a few hundreds in their molecular weight, and usually average less than that level.

If the carbon atoms are represented in the usual statical way by formulæ so as to get

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a model by which to visualize the process, the manner in which this occurs can readily be shown. But it is ever to be remembered that because a model, or formula, can be set down upon paper it does not follow that the reaction will occur. The occurrence or non-occurrence of the reaction depends upon the balance of energies within the radius of action of each atom, which behaves much like an infinitely small planet, or sun, in relationship to other planets in the molecular microcosm. Remembering this carefully, we may illustrate a scheme whereby molecules such as exist in living cells, may be built up.

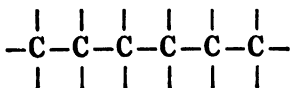
It is a curious fact in nature that there seems to be a position of greater stability when groups of six carbon atoms unite in little galaxies or concatenations. Other groups than those of six do exist, but they are not so stable nor so easily formed under natural conditions such as obtain in living organisms. Although such groups of less, or occasionally more, than six carbon atoms are formed naturally by life processes, by far the greater portion of the substance of living organisms is built up of six carbon groups and multiples of these.

There are two main types of six-grouped carbon atoms, which the organic chemist

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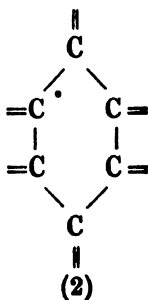
represents conventionally by open and closed chains of atoms, and these he calls fatty or aliphatic groups, and benzene or aromatic groups, respectively. Representing the carbon atom by the letter C and its four dynamic affinities by short lines, which, when they run from one carbon atom to another, show centres in interplay with one another, and when they are attached at one end only show free centres open to combine with other atomic groupings or atoms, then the two types of six-grouped carbon atoms may be illustrated by these two formulæ :—

Aliphatic.



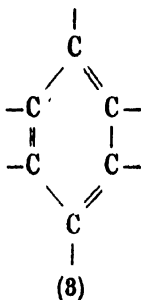
(1)

Aromatic.



(2)

The aromatic group in this simplest form is very unstable, and becomes more stable when each alternate interplay between the carbon atoms becomes doubled, thus :—



so leaving each carbon atom with only one free centre of activity.

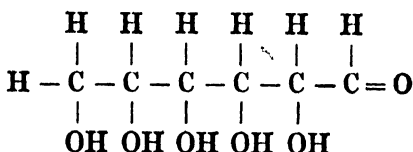
Now these formulæ do not represent actual organic substances, but only structures on which molecules can be built up; none of them can exist unless the free activities are taken up by other atoms or groups of atoms. Take the simplest case, that each of the free positions is taken up by a hydrogen atom (H). Then the schemes represent actual existing bodies called hydrocarbons. The third one would represent the molecule of the well-known substance benzene, or benzol, the first one a known hydrocarbon, hexane, and the second one a reduced benzene (hexa-hydrobenzol).

Very many other groupings than simply putting in hydrogen atoms can evidently be made, and hence without any reduplication

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a large host of organic compounds can be made.

As an illustration of this, if instead of two of the hydrogen atoms at one of the end carbons of the formula (1) an oxygen atom (O) be put in, and for one of the hydrogens on each of the other carbon atoms the atomic group called hydroxyl, consisting of an atom of oxygen and one of hydrogen ($-O-H$), which acts as a monad, be introduced, the formula becomes :—



and this is the formula of the simplest sugar known to us. Next, if two such whole big molecules as the one we have just developed, are united by setting free one of the places occupied by a H in one, and one of the places occupied by a HO in the other, then very simply a reduplicated molecule is formed, while the H set free from the one and the H O from the other unite to form a molecule of water $H-O-H$. The sugar so formed would be a disaccharide similar to cane sugar, or the sugar found in milk.

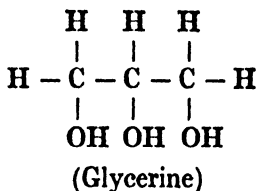
But this reduplication can evidently go on so long as energy conditions in the reduplicated molecule will allow of it. On paper a thousand such reduplications could be set down easily, and so theoretically a molecule as huge as a world could be built up, but such a structure has, in actual fact, a limit at which it breaks down on account of instability. The exact limit at which instability stops the process is unknown to us, but this is the simple way in which nature builds up starches in living plants. Such starches possess at least thirty to forty such groups, so simply joined together. This is a good example of how this step in the process of evolution towards life builds up molecular structure, and it may be premised here that such structural change is accompanied by great changes in the energy phenomena of the matter forming the molecule.

There are three great divisions of the organic bodies built up by living plants and animals, called carbohydrates, fats, and proteins, respectively. These are the commonest, and build up the great bulk of the living organisms. In addition to them there are other indispensable things, as will be seen later. It will, however, be sufficient here, if we gain some idea of how these three great classes are made up.

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An outline has been given above of the relationships of the sugars and starches. These together form the carbohydrates, those of the fats and proteins may now be considered so far as they come within our line of thought.

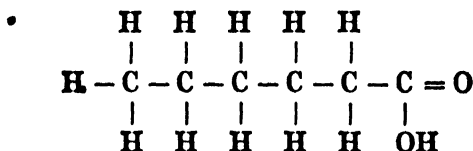
The fats of living cells consist of one group called glycerine, which behaves as a trivalent base united to three huge groups of a univalent or monad acid. The glycerine is simply a three carbon chain, in which each carbon atom is united to a hydrogen atom and a hydroxyl group (H O), thus :—



when the fat is formed in nature, each OH group is replaced by a molecule of the fatty acid. In this process a hydrogen atom is set free to unite with the HO from the glycerine to form water, much as the reduplication of the sugar molecules to form water was seen to occur above. So we have now only to elucidate the nature of this fatty acid which is to combine with the glycerine. If the formula (1) be written down again, with hydrogen

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atoms in all the available spaces of the carbon affinities except those of the atom at the end of the chain, where, instead, an oxygen atom and an hydroxyl group are placed, then the formula of a fatty acid is obtained thus :—



It is the group represented on the right-hand side, with one carbon, one oxygen and one hydroxyl, which gives the acid properties. This group is known as the *carboxyl* group, and always confers acid properties throughout the organic world.

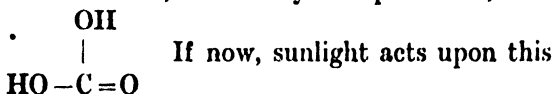
Here, then, we have an organic acid, and if three such molecules, each losing the H atom of its acidic group, unite with the glycerine molecule, each replacing a HO group in that body, which unites with the H atom to form H—O—H then there arises a fat. It has only to be remarked that the actual fatty acids formed in nature, are usually three times as large as this one, by the union of three six-carbon chains, only one of which possesses the acid group. The union may be visualized as

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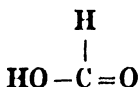
an end-to-end affair, so that a row of carbon atoms eighteen long instead of six, is obtained, with the acid group at one end. It is obvious what a huge molecule nature constructs when she produces a fat ; it is also clear on what a simple basis it is achieved by simple reduplication between these very simply constructed, large moleculcd, fatty acids and the glycerine molecule.

Setting aside the smaller differences at the ends of the linkages, and where unions of the big groups occur, it is obvious that the oft-repeated structure in the carbohydrate is the carbon atom united to a hydrogen and a hydroxyl group, while in the fat it is a carbon atom with two hydrogen atoms. Nature is always engaged building up carbohydrate into fat, because it is a more valuable storehouse of energy, and, weight for weight, gives out twice as much heat, or other form of energy to the body. What is the simple process by which it is accomplished ? By input of energy a HO group is taken away, and a hydrogen atom put in its place. This means discharge of oxygen and replacement by hydrogen. The chemist calls such a process reduction. Reduction is Nature's plan for building up these organic bodies, and so saving up energy for later use " while

the sun shines." Sunlight energy is taken, water broken up, its hydrogen built up with the carbon of carbon-dioxide into an organic substance. Then, on reversal of the process, this organic substance can be oxidized again, yielding once more its hydrogen as water, its carbon as carbon-dioxide, and its energy for the life-processes. The process by which the green plant first builds up carbohydrate may be represented very simply; if the carbon-dioxide from the air passes into union with the water in the plant juices there is formed carbonic acid, which may be represented, thus



If now, sunlight acts upon this splitting up one of the O II groups and replacing it by H, the oxygen being given off by the plant to the air, the formula becomes



This is formic acid, and contains the characteristic carbohydrate grouping, carbon, hydrogen, and hydroxyl united together. When it is again reduced and united up with others to form a six carbon chain, a carbohydrate is the result.

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Fat formation, as stated, is only a continuation of this reduction process with still more storage of energy.

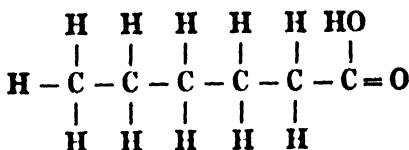
Now the last group of the three great organic divisions is approached; this is the central group in the life structure, and absolutely indispensable in all living plants and animals. It is the very citadel structure of the cell's life. The group of the *proteins* differs from fats and carbohydrates, which only contain carbon, hydrogen, and oxygen, in that it also contains nitrogen, and sometimes also phosphorus, sulphur, iron, and a few other common elements. Around these central proteins the carbohydrates and fats and all other constituents are united, in the manner to be described in the next chapter, to form the living machine.

Enormous complexity and differences, such as would require a large volume for their description, arise in the formation of the thousands of proteins known to the biochemist. But if detail be abandoned a very simple picture of the chemical building stones from which the protein edifice is constructed, and of the artifice by which these are built up into the proteins, can easily be presented even to the non-chemist.

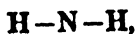
In describing the constitution of the fats,

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the nature of the organic acid had to be mentioned, and the formula of one with six carbon atoms was set down. It was represented by a chain of carbon atoms, united to each other by two affinity centres, and with the other centres satisfied by hydrogen atoms, save in the case of one of the terminal carbon atoms, where, instead, was found the acidic group in which one hydroxyl group (HO) and one oxygen atom (O) held the available affinities, so giving the formula:—



This is an acid, but if now the substance, ammonia, represented by the formula,



$\begin{array}{c} | \\ \text{H} \end{array}$
 be taken and supposed to have lost

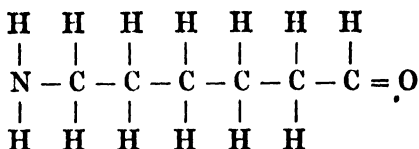
one of its hydrogens, it then acts as a monad

$\begin{array}{c} -\text{N}-\text{H}, \\ | \\ \text{H} \end{array}$
 group which can replace a hydrogen

atom in the above formula. This can be done experimentally by means which need

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not here be described. If it be supposed that this group, called amidogen, takes the place of the hydrogen atom at the extreme left in the formula of the acid shown above, then the formula becomes :—



By means of this quite simple formula, the structure of the proteins can readily be explained, and also many of their peculiar properties which enable them to play their part in the phenomena of life.

Ammonia, as every one knows, is a strong base which neutralizes acids, and if it had merely gone into the acid group at the other end it would simply have neutralized the acid. But now the acid group is there intact, and at the same time at the other end there is a molecule introduced, the amidogen, or $\text{H}-\text{N}-\text{H}$, which confers alkaline or basic properties. Here, then, is a new kind of body, which is acid in one part and basic in another, and with neither property neutralized.

The molecule has taken on a kind of chemical polarity, or duality, like a magnet.

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Such molecules, like tiny magnetized iron particles, can almost adhere together.

This peculiar chemical body so evolved is called an amino acid, and amino acids are the basis for all the proteins. There are many different types and thousands of individuals, and these can build up a legion of protein forms. It is most remarkable that here also the peculiar property of the carbon atom to be most stable in galaxies of six again comes in. There are many exceptions, but six is a very favourite number of atoms for the amino acids to contain, and the bulk of the mass of any protein molecule is built up of amino acids with six carbon atoms in the molecule, the hydrogen atoms represented in the type formula shown above, may be replaced by many diverse groups, so swelling the host of individuals. So long as there is an amino group and an acid group the remainder may be arranged on many schemes.

Sometimes there are two amino groups instead of one when the amino acid is called a di-amino acid, also there may sometimes be two acid groups. Some such di-amino groups occur in all proteins. In the schematic formulæ, these di-amino acids furnish opportunities for branching or side-chains, so that

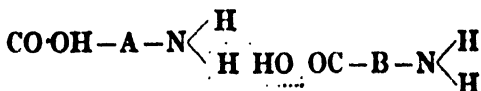
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the formula instead of a long simple chain branches out in a tree-like way. The formula, as has often been insisted upon, is only a visualizing model, but this property occurring in the model, suggests that the di-amino acid, in actual nature, may furnish a device for changing the relationships in space of the huge growing protein molecule and rendering it more stable than if mon-amino acids alone were present. When di-amino acids are present the giant molecule may remain dynamically stable up to a higher level.

The mon-amino and di-amino acids form the building stones for the construction of the proteins, and the manner of their doing so is exceedingly simple. Each one has a basic portion, and an acid portion. The acid portion of the one has chemical attraction for the basic portion of the other, and they condense or unite just as the two simple sugars have been seen to unite to form a di-sugar, and the di-sugars to unite to form poly-sugars, otherwise called starches, or celluloses of the plants and animals.

If the two letters A and B be used to represent the changeable body part of each amino-acid so uniting, the constant acid group be represented by the letters indicating the elements in it as COOH, and the constant

basic group similarly, as $\text{N} \begin{smallmatrix} \text{H} \\ \diagup \\ \text{H} \end{smallmatrix}$, then the union can easily be shown graphically, thus :—



An acidic and basic end come together, the elements of a water molecule are detached, as indicated by the dotted line, and all the rest forms a reduplicated amino-acid.

It is to be noted next that the whole larger complex is still an amino-acid, for at one end it has still an acid group, and at the other a basic group. The process is analogous to two magnetized particles coming together by a north and a south pole, when the double particle has still a south and a north pole, and hence is still a magnet.

This process can go on so far as molecular stability will allow, and the products formed are called polyamino-acids, or, as the master-worker at them, Emil Fischer, suggests, they may be called poly-peptides, from their resemblance in their properties to the natural products obtained when proteins begin to be disrupted by pepsin in digestion in the stomach.

Fischer and his co-workers have made artificially some hundreds of these poly-

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peptides, and the higher members closely resemble proteins in their chemical nature.

In the formation of the true polypeptide, there is a real chemical condensation, with true atomic union, and a certain amount of disruptive force is necessary to achieve this. In the living cell, energy obtained by oxidation of other substances is utilized to do this, and in the laboratory the chemist does it by having present substances greedy for water. But as the molecule grows in size, it will attain a size at which the reverse process of disrupting with uptake of water tends to occur, and a position or degree of complexity will establish itself at any particular environment where a balance holds. In the neighbourhood of this balancing point, a condition may arise where two polypeptides come together, as illustrated, but no atomic union can occur. There is not sufficient energy to detach the H and OH groups and condense. Under such conditions, the two molecules may remain feebly held together without true atomic union as a kind of dual molecule. This having occurred, the dual molecule still has a free acid group and a free basic group, and the acid group can enter into loose molecular relationship with the basic part of a third molecule, while the basic one can play

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a similar part with the acid part of a fourth molecule. Now there are four molecules, and still there are free attachments for more, for each of the new molecules has a free active portion. If a certain percentage of the molecules so aggregating are either di-basic acids, or have two amino positions to act as a double base, this system can branch in all directions in space.

Accordingly, without true atomic union between them, there may be ten, twenty, thirty, sixty molecules forming a great aggregate molecule. This is the form in which proteins occur in living cells, and is an example of an organic colloid.

A most important point to note here is what the chemist calls the "lability" or "mobility" of such a colloid. Its strength for the purposes of the vital phenomena lies in its very weakness as a chemical body. It exists in a state of the most delicate balance, ready to play in and out, and vibrate like a piece of mechanism, only far more delicately, responding to every change in its environment. Its dimensions as an aggregate, and the constitution of its parts depend on its environment, and especially upon its nutrition. It must, once it has been constructed, be fed with the proper pabulum, nothing must

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be offered which will unite too strongly and lock up its activities. Material must be given to it adapted to its uses, or upon which it can play and produce either its own building materials, or obtain energy for its constant cyclical changes.

There is, here, a near approach to the life material, and it is to be observed that function and activities alter and new creative phenomena develop with developing structure.

These living properties depend on labile molecular unions, and are not only found in living structures, they are to be met in inorganic colloids.

It has been seen above that with the exception of carbon, and in a lesser degree silicon, the other elements do not possess in any marked degree the power of self-union, and so do not form enormous single molecules such as fats, carbohydrates, and proteins, but many of them do possess the power of molecular union to form colloids with as many as sixty molecules united without any atomic unions to form colloids.

The compounds of carbon possess both these properties for increasing structural complexity viz., large molecules and power of colloidal union, and hence these form the best material

in nature for the construction of living organisms.

Before passing on to the energetics of living matter, some consideration must be accorded to the problems of molecular combination and the formation of colloids, for all living structures consist of colloids. Such colloids are either active in solution in water, or are dead inactive masses formed by the dissolved living colloids and thrown out as supporting meshworks, mechanisms for support, and membranes surrounding and dividing off the living units or cells from one another. Thus, both in that grosser mechanical structure visible under the microscope which holds the organic unit, or cell, together, and in its ultra-microscopic intrinsically living and active part, the living organism is made up of colloidal matter.

CHAPTER VI

EVOLUTION OF COLLOIDS

THIS chapter in the history of evolution is one that has suffered, until quite recently, from a strange neglect, at the hands of both

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chemists and biologists, although it happens to be that one which lies at the very threshold of life. It was opened just fifty years ago by Thomas Graham, who introduced the word colloid because one of the most typical members is gelatine (L. colla, glue). This earliest pioneer with a wonderful clearness of vision recognized the close relationship of colloids to the phenomena of life, and with such a lead it is remarkable that the study was left languishing for nearly forty years. In the last decade it has become a centre of feverish industry with ever-expanding relationships both to modern industries, and to the scientific problems of bio-chemistry and medicine.

One reason for this neglect undoubtedly lay in the fixed attitude of the chemical theory of the time towards the subject of atomic valencies. It was deemed inconceivable that a fully saturated chemical substance, in the atomic sense, could enter afresh into a new round of chemical activities, in which atoms as such did not play a part, but where the whole molecule behaved as an atom. In fact, to the majority of chemists, this is still a heterodox opinion, and they prefer to ascribe such molecular actions to something which they describe as "residual affinity."

Legions of cases exist in which two or more molecules, themselves completely saturated atomically, and incapable of attaching to their molecule a single additional atom, unite most strongly to one another with evolution of energy, and this without the loosening of any atomic affinities.¹

The theory of atomic valencies entirely fails to account for such combinations, and so through lack of invention and scientific imagination, they were simply cast upon one side and ignored by the chemist as *purely physical* phenomena, just as if that removed them from the pale of research by throwing them into the dust-heap of another scientist. The physicist was content to classify them with a confused heap of phenomena ascribed to surface reactions, or condensations upon surfaces, and having invented the term *adsorption* to designate such phenomena, the physicist, too, rested upon his laurels.

Now, in many cases, the amount of energy set free as heat, when a number of molecules, each completely saturated atomically, unite together is of far too high an order of magni-

¹ For details, the reader acquainted with chemistry is referred to a paper entitled "The rôle played by molecular affinities in bio-chemical reactions," Benjamin Moore, *Archivio di Fisiologia*, vol. vii., 1909. Anniversary volume in honour of Giulio Fano.

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tude to ascribe the result to a residual atomic affinity, which is absolutely powerless to add another single atom to the molecule, but can nevertheless set so large a store of energy free by uniting with another saturated molecule without any atomic displacements.

The experimental evidence is complete and convincing that these saturated molecules possess no remaining trace of *atomic* affinity, and that the molecular unions must arise not from atomic affinities, but from "molecular affinities."

Moreover, in such molecular combinations, between molecules behaving as units, there are found properties which exactly reproduce on the molecular scale, the analogues of the "atomic affinities" and "atomic valencies" described in the previous chapter, and these it is proposed may be called "molecular affinity" and "molecular valency."

Such molecular affinity and valency do not belong to any particular atom or group in the molecule, but are a property of the molecule as a whole.

Molecular affinity is a specific property just as is atomic affinity. Some pairs of molecules will not unite, under ordinary circumstances, to form molecular unions, so feeble is their

mutual molecular affinity; others unite violently with great evolution of heat.

As to molecular valency some pairs, or sets, of molecules will unite one to one, others two to one, and so on. Also, the relative numbers so uniting are fixed by the chemical nature of the reacting molecules, and, curiously enough, sometimes there are two ratios of union, just as it has been seen in the previous chapter that the same element may have two valencies, the lower one arising as a result of partial self-saturation.

The numerical values of molecular valencies often reach far higher figures than those of atomic valencies. It was pointed out that atomic valencies probably did not exceed a doubtful hexi-valency in a few elements. But an undoubted molecular valency in one saturated substance of twenty-four fold that of the other substance united with it, is seen in at least one group of molecular unions.

Doubt has been cast upon the chemical nature of these molecular unions, because it is difficult in many cases to prove that there is always a definite ratio in the numbers of the molecules aggregating together,

In all such cases it must be remembered that it is difficult to obtain the point where interaction between the substances is com-

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plete, and to remove the completed product from intermixture with incomplete stages, and from the two or more unchanged reacting substances. For these complex molecular unions give rise to matter in a new form which cannot be so easily dealt with. In many cases, when saturation is complete there are found to be exact molecular relationships, just as definite as those found in simple inorganic mono-molecules.

But the admission, even, of varying molecular relationships in the multi-molecule, does not preclude the reaction from being truly chemical. A new territory is here being investigated, and it would not be true philosophy to expect details to remain the same in this region as in the mono-molecular one. When molecules begin to interplay, instead of atoms, some modifications are naturally to be expected. Also the exact atomic relationships in the composition of a mono-molecule, on account of the low relative valencies of the atoms, can be followed with great experimental exactitude. But, when instead of atomic valencies rising no higher than four or five, there are substituted molecular valencies of thirty to sixty, then the problem of following out exact relative numbers of molecules of each constituent in

the multi-molecule, becomes experimentally almost impossible. It is easy to discover by analysis whether a mono-molecule contains three or four atoms of a given element, but the query as to whether a given multi-molecule contains sixty or sixty-one molecules of a given substance is obviously more difficult of solution. The same difficulty is found in the region of the mono-molecule, such as those dealt with in the last chapter. When there are over twenty atoms of hydrogen in the molecule of a fatty acid, the chemist is often unable to determine from the results of an analysis, whether the figure assigned in the formula should be, say, twenty or twenty-one. Finally, it is to be remembered that even in inorganic chemistry, compounds are to be found in a similarly constituted series with varying numbers of atoms, and accordingly the occurrence of a series of molecular combinations between two saturated molecules with varying relative numbers of molecules is no good evidence against the chemical nature of molecular combination.

All molecular combinations do not lead to the formation of colloids: indeed, molecular combination in the case of the greater half of the inorganic substances known as crystalloids (as distinguished from colloids) forms

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the initial step in crystal formation. The distinguishing feature of the colloid is that the molecular unions shall be of a feeble unstable kind with very little evolution of energy. This condition has been termed the meta-stable condition, and is seen at its acme in living colloids. The true inorganic colloids showing typically those characteristic properties which distinguish the colloidal class from the crystalloidal class of bodies are also formed without much evolution of energy. Between the two classes lie all kinds of intermediate grades, and it is only by contrasting a typical colloid with a typical crystalloid that those characteristic features have become obvious which will presently be described.

Crystallization of a substance from solution in well-formed crystals of definite form is usually regarded as one of the best criteria of definite chemical constitution and purity. As a rule, to which there are some notable exceptions, colloids do not form saturated solutions like crystalloids, and then crystallize out giving an increasing crop of crystals as the solvent evaporates off. After crystals once begin to form in a solution of a crystalloid, the mother liquor over the crystals remains of a constant concentration, and this

is preserved by the crystals growing larger and increasing in number. In a solution of a colloid as a rule no saturation point is reached, the solution becomes thicker and thicker, and finally forms a viscid gum especially at lower temperatures, and the gum holds tenaciously to the last portions of the solvent. As typical examples there may be mentioned aqueous solutions of common salt (a crystalloid) and of ordinary gum arabic (a colloid). Having defined this property of crystallization as something properly typical of crystalloids, which caused Graham to give them their name which distinguishes them from colloids, let us now briefly take up the subject of molecular combinations, molecular affinities and molecular valencies, before passing on to the consideration of the other main properties of the colloids.

As a typical example of molecular compounds amongst crystalloids, there may be taken three crystalline substances, closely related chemically, viz., sodium chloride (common salt), sodium bromide, and sodium iodide. When their respective solutions in water concentrate, each substance, at a definite concentration in each case, separates out in crystalline form from the water. Now each of these salts is completely saturated

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atomically, the molecule consisting of only two atoms in each case, and these atoms monads. In each case there is in the molecule one atom of sodium united respectively to one of chlorine, one of bromine, and one of iodine. A clearer case of atomic saturation could not be found; there is no known way by which an atom of any kind can be introduced without splitting up the molecule. When the three crystalline salts separate out from their three respective saturated solutions, it is found, however, that while the sodium chloride molecules have formed themselves into crystals consisting entirely of sodium chloride, the sodium bromide and the sodium iodide have separated in crystals containing water. Analysis of these latter two kinds of crystals, moreover, demonstrates that the bromide and iodide and their respective amounts of water are so beautifully proportioned that there are in each case exactly two molecules of water to each molecule of salt. This does not mean that there is the same percentage of water in the sodium bromide as in the sodium iodide crystals, for the sodium iodide molecule is much heavier than the sodium bromide molecule. But when the percentages are worked out on the basis of molecular weights, then it is

discovered that the molecules have united *exactly* in the ratio of two molecules of water to one molecule of bromide or iodide, respectively.

But this is precisely the proof upon which the whole atomic theory rests, by means of which Dalton proved that in *atomic* reactions, union occurred always proportionately to atomic weights, or their multiples. If the argument holds for atoms, it is difficult to see why it is to be refused for molecules.

In this reaction both salt and water are completely saturated compounds, and they unite without any atoms being displaced or set free. Specific molecular affinity is shown by its absence in the case of the sodium chloride, and its presence in the other two cases. Molecular valency is also illustrated by the exact relationship of two molecules to one. The two salts possess an equal molecular valency which is double that of the water molecule.

The facts as to true chemical union are also demonstrated by the large amount of heat set free when the molecular union between the salts and water takes place.

The quantitative difference in the amount of molecular chemical affinity is easily shown by measuring the amounts of heat evolved in

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the two cases. If the crystalline salts are heated above the temperature of boiling water, the water of the crystals (water of crystallization) is driven off, and the dry or anhydrous salts are obtained. When these salts are allowed to cool and then mixed with just enough water to form once more the crystals, the mixture as it crystallizes grows quite warm.

When the chemist measures such quantities of heat, he uses a quantity of the salt equal to the molecular weight of the salt in grammes (the unit of weight of the decimal system), and he expresses the heat developed in units, which he terms calories. The calory is the amount of heat required to heat 100 grammes of water by one degree Centigrade, and is written down as K in the chemist's shorthand. Now when an amount of dried sodium bromide expressing the molecular weight in grammes (*i.e.*, about 110 grammes), is allowed to unite with twice the molecular weight of water in grammes (*i.e.*, 86 grammes), the amount of heat developed is found to be 45 K, or an amount of heat approximately sufficient to heat 45 grammes of water from freezing point to boiling point.

The figure for the iodide is higher still, standing at 58 K.

Here, then, is conclusive proof as to these molecular affinities and valencies. The chloride has no measurable affinity, and separates without water, the bromide and iodide have specific and different affinities, and a molecular valency double that of the water molecule.

This is not an isolated case ; the majority of inorganic crystalline substances show the same effect, and exhibit specific variations in molecular affinity and molecular valency. Here are a few examples from the wealth of them in the literature :—Calcium nitrate, four molecules of water, 112 K ; manganous sulphate, five molecules, 138 K ; nickel chloride, six molecules, 203 K ; magnesium sulphate, seven molecules, 241 K ; barium hydrate, eight molecules, 254 K ; sodium carbonate, ten molecules, 217 K ; alkaline sodium phosphate, twelve molecules, 284 K.

These examples prove both varying molecular valency from substance to substance, and also varying molecular affinity, and the basis of proof is exactly that admitted for the atomic analogues.

Common experience proves the same thing, when almost any crystalline body is dissolved in water, the solution is cooled thereby. The cause of the cooling is that the dissolved substance produces a pressure in the solution

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just as if it had been compressed into a steel gas cylinder, the pressure so developed within the solution being called *osmotic* pressure. This pressure means work done, and the energy must be got from some other form. It is obtained by the cooling of the solution. If now, instead of the crystallized substance, an equal amount of the *dried* salt be used, then the temperature, in practically every case, rises instead of falling, showing that the energy set free by the molecular affinity of the anhydrous salt and water, is greater than the energy needed for the development of the osmotic pressure energy. In fact, the figures given above, in each case only express the *difference* between these two amounts of energy, and the true molecular affinity is measured by an amount greater than them, at present unknown to us.

By what scheme can this molecular affinity and valency be visualized? The human mind always searches for some outward and visible sign of a scientific faith, so here is a simile.

Suppose the electrons and atoms and molecules could be magnified by a powerful microscope that would make the electrons visible to the eye, then it may be supposed that a system might be revealed such as the

telescope displays to the astronomer. A solar system might be seen representing the molecule, the sun and its attendant primary planets would indicate the atoms, and the satellites of the planets would stand for the electrons. Closer examination under this imaginary microscope might reveal that the sun and the attendant planets, and their satellites, were, *as a whole*, revolving in concert with other suns and other solar systems, and this latter motion would represent molecular affinity. The variations in numbers in the various systems in equipoise would stand for chemical valency at each stage. Some planets would have only one moon, others four, in a solar system the number of planets might vary, and in the constellations there might be similar balances amongst the constituent-solar systems.

It is, perchance, but an analogy, but it is one which fittingly illustrates the facts of the case.

Water is not the only substance which forms these molecular unions with crystalloids, alcohol and other organic substances may replace water of crystallization, or, apart from water, different crystalloids which come out of solution in the same crystalline form can replace each other in the same crystal.

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An example of interest to the biological chemist, is the molecular union of one molecule each of common salt and grape sugar, which separates in crystalline form from a common solution of these two substances, and this is but one instance amongst many occurring in the body, too specialized to give in detail in a general volume.

With this outline sketch we may leave the question of molecular unions amongst crystalloids, and pass on to the remaining properties of colloids.

All the known properties of colloids can be traced to feeble molecular affinities between the molecules themselves, causing them to unite into multi-molecules or "solution aggregates," and to a balance between such affinities and similar feeble affinities for crystalloids in common solution with them, and for the molecules of the solvent. The whole essence of the colloidal condition is that of a balance of play of energies in the most delicate equilibrium. Quantitative differences exist, giving classes of colloids which differ from one another in stability. Some are upset with the greatest ease by either adding a slight excess of crystalloid to the solution, or by heating the solution a few degrees in temperature, others more delicate still even undergo

slow spontaneous change when left to themselves. On the other hand, colloids are known of great stability which are not easily upset even by boiling their solutions, or by saturating them with salt.

These variations are a peculiarity of the colloidal state of great importance in relationship to the phenomena of life.

A great many colloids show two distinct forms of arrangement of their multi-molecules, known respectively as *hydrosols* and *hydrogels*. Thus a solution of glue or gelatine at such a temperature that it is fluid and mobile is a hydrosol ; at a lower temperature it sets into a solid jelly, and is then a hydrogel. The clear fluid part of the blood, known as plasma, or the clear uncooked fluid of the white of an egg contains its nutrient protein substances in the form of hydrosols. When either fluid is heated nearly to the boiling point of water it sets into a solid jelly and then forms a hydrogel. The effect of temperature it will be noticed, is in the opposite direction : in the gelatine, which becomes fluid at the higher temperature, while the egg-white and blood-plasma set solid or coagulate at the higher temperature. There is also this important difference that the process is reversible in the case of the gelatine, which is hence

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called a reversible colloid; while in the other two cases the hydrogel (or coagulum, as it is also called), is permanent, and a hydrosol is not again formed as the temperature falls.

In the condition of the hydrosol, the multi-molecules, or solution aggregates, are each free and microscopically invisible, and so far as the properties of solution are concerned, each behaves as would a single unit, or molecule in solution. When gel formation occurs, the multi-molecules aggregate together and form a system made up of two distinct kinds. It is called a diphasic system, and is no longer a true solution. It is in this way that there arise foam structures, and the protoplasmic networks and structures seen in living cells, and also as artifacts, or products of death and fixation by chemicals, in dead cells. When the colloidal solution, as a result of changes in environment, forms two phases, it does so by separating into two systems, in one of which there is still a true solution, but a comparatively dilute one, of the smaller multi-molecules, and, in the other, relatively huge molecular complexes have separated with comparatively little of the solvent. In the limit, the fluid part may be pure solvent and the particulate part pure colloidal

matter without solvent. This di-phasic separation is very interesting because it illustrates so many of the origins of the structures shown by the microscope in cells, and in colloidal solutions and suspensions in general. If the greater part consists of the fluid phase when separation occurs, then the particulate part may either gather into little spherules so widely apart that they do not touch, then an emulsion is the result; or there may be just such proportions, that the concentrated phase forms a meshwork between small spheres of the dilute phase. In this way a foam or a reticulum may be formed, and the meshwork according to circumstances of physical and chemical environment may take many forms. Again, the more concentrated phase may predominate, surrounded by a lacunar setting of fluid, when a *granular* network results, coarsely or finely granular, according to the degree of size of the aggregate of semi-solid material. These varieties may all be recognized by the histologist, when examining the microscopical appearances of cells. From such causes, differences in staining with histological reagents and in the appearances with polarized or reflected light arise, and these are indispensable aids in differentiating

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and diagnosing various kinds of cells, and in recognizing under the microscope the micro-organisms which produce disease.

A division of colloids has been mentioned above into reversible and irreversible, but it is probable that even irreversible colloids, if treated delicately enough, can be reversed if the process is not carried too far. This has been shown by the aid of the ultra-microscope, using one of the protein bodies of the blood plasma. If a solution of this colloid placed in the field of the ultra-microscope, be cautiously warmed to just below the point of temperature which would cause it to coagulate irreversibly, then it is observed that the view which was previously clear becomes suddenly filled with an innumerable host of moving particles which rapidly increase and become more prominent. If at this stage the heating process be stopped and the solution allowed to cool slowly, as the temperature falls all these particles dissolve and disappear, and this appearance and disappearance can be many times repeated. If the heating be carried so far, however, that particles visible microscopically even to a high power of the ordinary microscope are formed, then the process ceases to be reversible.

This observation is one of high import in relationship to rhythmic processes, which occur in many forms of living cells, such as the nerve cells that guide respiration, and the cells of contractile tissues like those of the beating heart.

•The view was foreshadowed long ago by Sidney Ringer that muscular contraction is an incipient coagulation which becomes reversed and again repeated in cyclic alternation. This view was suggested by similarities in chemical character between the products of muscular contraction, and that coagulation of the muscle juices which causes muscular stiffening or *rigor mortis* after death. Heat is not the only cause which can induce incipient coagulation; a slight change in chemical reaction from alkaline towards acid causes opalescence due to a running together of the colloid into larger aggregates, which commence to be big enough to interfere with the light waves, and so cause opalescence. If the amount of acid be increased the opalescence passes into true coagulation. Now a living cell, such as a nerve-cell, may furnish rhythmical stimulation to another, or itself show rhythmical contractions, as in the case of a muscle-cell, because it heaps up between each contraction as a result of the chemical

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changes going on within it, such feeble acids as carbonic or lactic acid. This leads to molecular aggregation of the colloids of the cell, and this culminates in a stimulus or contraction in which the acid is discharged, and the whole system reverses or reverts to its original condition.

It is thus seen that in the typical colloidal solution there exists a most delicate balance of the feeble affinities of the colloidal molecules, so that within narrow limits they can build together or be pulled apart, and the value of this in life processes is obvious.

Next there must be considered the balancing of these affinities against similar affinities for the solvent and for the crystalloids of inorganic or organic nature present in true solution along with the colloids.

The affinity between colloid and solvent is shown by the failure to form saturated solutions and separate out as crystalloids do; it is also shown by the tendency of the colloidal multi-molecules to accumulate upon any interface and alter conditions there. Such accumulations are accompanied by change in what is called surface-tension (or the energy distribution at the interface between two layers). It is as a result of this that colloidal solutions readily form froths, even in most

dilute solutions, for all the colloid tends to accumulate at the interface. The frothing of soap solutions, and of all albuminous solutions, with formation of a lather of bubbles is an example of this, and what happens between air and a colloidal solution can also happen between such a solution and solid or fluid particles suspended in it. Such an effect is seen in the suspension of fat in milk or cream. Colloids such as gum arabic are similarly used by the pharmacist to hold solid drugs in suspension.

When the colloidal particles have once been attracted into the surface layer they form a highly concentrated solution or fluid film there, and such concentration leads to formation of solid films as well as to the synthesis and building up of more complex substances in living cells.

High concentration in the surface layer acts much as increasing pressure does in causing gases to liquefy or condense, and favours chemical union.

An example of such action is seen in the skin which forms, and again re-forms as often as it is skimmed off, on the surface of a glass of warmed milk while cooling, or on a cup of cocoa and milk. Familiar as this observation is, it furnishes an example of the manner in

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which unicellular organisms often form their external envelopes, and of the manner in which cells provide themselves with limiting membranes or cell-walls.

The chief colloid of the milk, on account of its affinities, accumulates on the surface, the accumulation gives increased concentration, the pressure of the increased concentration causes the multi-molecules to build together, the larger molecules fall out of solution as particles, and these join to form a close network or film.

Nor is it only film formation and delimitation of the constituent cells of an organism from one another that is served by this property of colloids of concentrating at an interface. Such interfaces occur on the surfaces of the minute microscopic granules which are found in all living cells. Here also there concentrate not only ordinary colloids present in solution within the cell, but bodies formed by the cell called *ferments* or *enzymes*, themselves also colloids.

This concentration within the cell on surfaces favours union, and it is in this way, by continued aggregation, that starch granules, protein granules, and drops of fat or oil, grow within living cells.

It is a wonderful adaptation of nature that

these ferments which produce union and reduplication within the living cells, are exactly the same substances which digest and break up the food when they are thrown out by the digestive glands into the alimentary canal, and so form soluble matter capable of absorption.

The food must be broken down into chemical building stones from which the animal can rebuild its own special and very specific colloidal structures, which vary from one species of animal to another. This chemical detachment is achieved by means of soluble ferments, or enzymes, discharged by the cells of the digestive glands. In dilute solution these attack the starches, fats, and proteins, reversing the building up processes described in the previous chapter. The smaller molecules so formed are taken up into the body and reach the cells. They undergo local concentration in the cells, and these being brought again in contact with exactly the same ferments, also locally concentrated on surfaces, exactly the opposite effect occurs, and the building back into multi-molecules commences. In dilute solution there is breaking up, in concentrated solution there is condensation and re-duplication. It is only when chemical unions are feeble and small

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amounts of energy are absorbed or set free that chemical energy and pressure energy (or energy of concentration) can balance in this remarkable way.

The balance so established enables the living cell to deal with its nutrition and preserve a nearly constant amount of soluble pabulum within its contents. Suppose the living cell is supplied with more nutrition than it requires at the moment for immediate oxidation to yield energy for its life-processes, then the increased pressure of the soluble part causes condensation on the multi-molecules of colloid. This concentration, aided by the ferments, causes reduplication, and building-up of fats, starches, and proteins into more multi-molecules, and finally granules are formed.

Now, suppose supplies of nutrition decrease or fail, then the cell uses up its soluble material, so obtaining energy which it converts into various forms of activity. As a result, the pressure of soluble matter decreases, now the enzymes commence to act upon the multi-molecules and break them up into soluble material to restore the balance and supply a store of energy for the active dissolved colloids to utilize for the life-processes. In this way slight variations in environment

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determine a movement upwards or downwards in these delicately balanced colloidal compounds.

Another factor in the chemical reactions of the colloids which differs from that of simple inorganic relationships is the *time* taken for the changes. A reaction in which there is a great change of energy comparatively, for a small amount of matter altered, runs very swiftly. Hydrogen and oxygen unite to form water with a practically instantaneous explosion, and then all is over and the system is inert. A moment of fierce activity followed by absolute rest. But in colloidal reactions, there is slow movement of the reaction for days. In many cases it is never complete, and slight changes acting on the system can send it slowly pulsating up and down about an equilibrium point.

Such changes are seen even in inorganic colloids, such, for example, as colloidal silicic acid, as studied by Graham. Silicic acid as ordinarily obtained, readily gives up water and forms silica, of which flint and sand are composed. This substance, needless to say, is insoluble in water, but if treated with strong alkali it forms alkaline silicates. An example of such is sodium silicate, better known in solution in water as water glass, now used

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somewhat extensively for commercial preservation of eggs. If dilute acid be added cautiously to this substance silicic acid in a water-soluble form is produced. If a solution of this silicic acid be placed in a tube made of parchment paper (such as is used for covering jam-pots), and the tube be suspended in a stream of running water, the solution may practically be freed from the excess of acid used for its manufacture and from other impurities.

This was the method by which Graham first prepared colloidal silicic acid, and by somewhat similar methods, he also prepared a large number of other inorganic colloids in clear solution, and demonstrated that so far from being exceptional amongst inorganic molecules, the colloidal state is one of frequent occurrence.

Such colloidal solutions of inorganic bodies exhibit all the delicate properties described above, in regard to coagulation, etc.

Graham showed that the silicic acid solution behaved in all its chemical properties as if it had a multi-molecule, consisting of about sixty molecules instead of one, united into one chemical unit.

It still behaved as an acid, but a given weight of it only required about one-sixtieth

part of the proper amount of alkali to neutralize it, which it would have needed, if supposed to be composed of mono-molecules.

The huge molecules were unable to pass through the parchment paper in the method of separation mentioned above, although the acid and other crystalloids had passed through readily. This is a general method of separation of colloids and crystalloids. A colloid in solution is unable to penetrate a film of a hydrogel of another colloid placed in its way. The living cell makes great use of this property by possessing such a film. Inside the film of hydrogel it holds dissolved colloids or hydrosols so constituted that they can unite with certain crystalloids (such as the dissolved food-constituents, amino acids, sugars, fatty acids, glycerine, etc.). The hydrosols are kept within the cell by the hydrogel membrane and the crystalloids diffuse in. Once within they are either broken down by the hydrosols to yield energy, or built up into their substance as described above. This relieves pressure within and more crystalloid diffuses in. Certain inorganic salts also combine with the hydrosols of the cell, and so accumulate preferentially within it, such, for example, as potassium and phosphates.

This property of indiffusibility of the

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colloids was also suggested by Graham as a method, called dialysis, of separating colloids from crystalloids for analytical purposes. For example, such a crystalloid as strychnine can easily be separated from proteins and other colloids, in the mixed contents of the stomach, when investigations are being conducted in a case of supposed poisoning, and so minimal amounts may be detected in a mixture that looks at first sight a hopeless mess to analyze.

In many important industrial processes this property is now employed, and it is one of the most important of the colloidal properties from both theoretical and practical points of view.

When a solution of colloidal silica separated from admixed crystalloids by prolonged dialysis is examined, it is a perfectly clear and very limpid body, which remains so for some days, but very slowly it undergoes the process of coagulation and sets into a clear, slightly opalescent, jelly.

Graham's researches were published in 1862-4, and even at that early date he had realized the importance to the physiologist of the study of the properties of his new-found bodies, for colloids, as he says, form the active part of all living cells. Thus he states

that fat might be carried in the tissues in invisible, apparently soluble form in union with the colloidal proteins. The carriage of fat about the body was long a puzzle to the physiologist, for it is insoluble in aqueous solutions, and hence ought to have been easily traced, but its appearances and disappearances in many tissues without being seen in transit, formed a perplexing conundrum. Recent work on fatty changes and degenerations has demonstrated the exact truth of Graham's remark made a generation earlier. In our present concepts, the colloid of the cell possesses both fat and carbohydrate dissolved and united to protein, and forming a mobile colloidal whole, in which chemical oscillations are ever occurring and new products being elaborated. Carbohydrate and fat are equally indispensable with protein for the maintenance of life. If absent from the food they are manufactured from amino acids by the living complex of the cell.

Graham also points out that just as ferments during digestion disrupt and dissolve proteins, such as white of egg, so alkali dissolves gelatinized silica acid, by disrupting the colloidal union of its aggregates, and he calls his gelatinized colloids pectized colloids, and their process of solution "peptization," on account

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of this analogy. The solvent action is not one of complete passage to the crystalloidal form, for the amount of alkali necessary to give a clear peptized solution is only a small percentage of the calculated amount for neutralizing all the silicic acid into monomolecules. The solution of the gelatinized mass is due to a partial disruption only, with formation of smaller colloidal complexes. Each of these complexes is held in solution by one or more active crystalloidal molecules of the alkali, the two components so forming what is now termed a crystallo-colloid. Such crystallo-colloids play a most important part in the life-work of the living cells. Proteins have hitherto been spoken of in this volume as if they were wholly organic, but it has long been known that proteins as they occur naturally can never be obtained without an appreciable amount of inorganic matter. This inorganic matter, chemists for long agreed to regard as an impurity, and so it was called "protein ash." It varies from a half to two per cent. in the majority of proteins, and was invariably regarded as a nuisance by earlier physiological chemists, who were striving after *pure* products of constant composition. It did not fit in with their scheme of things. Modern research has,

however, shown that this is an intrinsic part of the proteins, a central part of the whole scheme, without which activity is lost and the whole mass becomes inert and dead. Ash-free protein, the dream of the earlier workers, is protein no longer in any of its essential properties. An isolated beating heart from which certain inorganic salts are washed out by an irrigating stream containing none of them, soon ceases to contract, but on restoring these inorganic salts the heart soon starts automatically to work once more. The same can be proved for all living cells, • the appropriate inorganic crystalloids must be there, and present in definite amount neither too little nor too much, so as to form the crystallo-colloids, or the living cells cease operations and soon thereafter perish.

This fundamental relationship of inorganic and organic constituents is interesting in view of the evolution of the organic world from the inorganic. It forcibly calls to mind that law of the evolution of the higher animal which records that the higher embryo passes rapidly through some of the lower forms of its ancient ancestors in its individual evolution. So, probably, living •matter is still unable to dispense with those simple inorganic sub-

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stances by means of which it first arose from inorganic nature.

Whatever may be the reason, simple inorganic salts are indispensable in all living cells, and exist in union with the proteins forming crystallo-colloids.

The peculiar energy properties of colloidal solutions and the bearing of such properties upon the life-processes were clearly expressed by Graham, who writes, "Their peculiar physical aggregation with the chemical indifference referred to, appears to be required in substances that can intervene in the organic processes of life. The plastic elements of the animal body are found in this class. As gelatin appears to be its type, it is proposed to designate substances of the class as *colloids*, and to speak of their peculiar form of aggregation as the *colloidal condition of matter*. Opposed to the colloidal is the crystalloidal condition. Substances affecting the latter form will be classed as crystalloids. The distinction is no doubt one of intimate molecular constitution. "Although chemically inert in the ordinary sense, colloids possess a compensating activity of their own, arising out of their physical properties. While the rigidity of the crystalline structure shuts out external impressions, the softness

of the gelatinous colloid partakes of fluidity, and enables the colloid to become a medium for liquid diffusion, like water itself."

"Another and eminently characteristic quality of colloids is their mutability. Their existence is a continued metastasis. A colloid may be compared in this respect to water while existing liquid at a temperature under its usual freezing-point, or to a supersaturated saline solution. Fluid colloids appear to have always a pectous modification; and they often pass under the slightest influence from the first into the second condition."

"The colloid is, in fact, a dynamical state of matter; the crystalloidal being the statical condition. The colloid possesses *Energia*. It may be looked upon as the probable primary source of the force appearing in the phenomena of vitality. To the gradual manner in which colloidal changes take place (for they always demand time as an element) may the characteristic protraction of chemico-organic changes also be referred."

The importance of these slow energy changes in colloids referred to in the above extract by Graham, half a century ago, and the capability of their alteration and travel in new directions on account of small changes in the crystalloidal environment, so giving

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rise to phasic variations in the energy processes of the living cell, are only now somewhat tardily receiving that attention and further study which they so richly deserve. Many of the hidden wonders of cell life undoubtedly are clustered around the relationship of colloid and crystalloid.

Variations in minute detail of colloidal arrangement in itself, and in relationship to dissolved pabulum in the shape of organic and inorganic crystalloids, lie at the root of the varying activities of the cells, and of all physiological and pathological changes.

CHAPTER VII

THE ORIGIN OF LIFE

THE origin of life is one of those primeval questions that have agitated the human mind throughout the ages. Some system of creation has formed a basic part of every religious creed in all lands, and the progress and advancement of a people at any given period are reflected in their beliefs on this subject. The general state of scientific thought and knowledge at different times is also indicated

by the writings of the contemporary philosophers upon this theme, and the growth of enlightenment from age to age can be traced in the changing beliefs upon the subject. The most beautiful tales of the mythologies of ancient civilizations cluster round this subject so mysteriously ingrained in the nature of the mind, and great truths have been handed down disguised in those common legends of all races, which deal with the origin of man upon the earth. Fascinating as are many of these attempts of the imagination and inner consciousness to evolve such a scheme of organic creation as might enable man more nobly to worship this great mystery, none of them appeal to the educated imagination so powerfully as the actual picture which modern science is revealing to our eyes, as a new and natural revelation of the Infinite.

The mystery is still there, and ever will remain, but the steps by which the beauties of creation were developed, and are still developing, are becoming visible; and the vision only fills every thoughtful mind with greater reverence for a power and a glory more fully revealed. No single creative act could fill the mind with half the awe and admiration evoked by this spectacle, in the heavens and upon earth, of continuous

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evolution of wonder upon wonder. Scientific myth and religious myth of past ages are alike to be honoured and preserved as the best attempts of the knowledge, or science, of past ages to look up to this mystery, to understand it, and to worship the highest. It becomes no man to scoff at these things, and the labourer in science who gets so lost in mechanical detail that he has no mind left for the grandeur of the whole design for which detail only forms the substructure, could he but appreciate, would gain in inspiration and incentive from a sympathetic touch of faith in that spirit which breathes through the whole universe, and gives life to his mechanisms.

Those who are inclined to think that the search after the mystery of life is illusory and leads no whither, or to no practical goal, have not studied the history of scientific advance with clear vision. The problem is not purely a philosophical one; on the other hand, it is an eminently practical and experimental one in itself, and the richest harvest that ever biological study yielded to mankind arose incidentally to an enquiry into the origin of life.

Just as the search for the philosopher's stone that was to transmute the baser metals

into gold, led through alchemy to the foundations of modern chemistry, and to a richer reward than the long-sought stone, and as the vain pursuit of the elusive *elixir vitæ*, that was to renew youth and vigour and give unending life at the prime, merged into the beginnings of scientific medicine; so the enquiry into spontaneous generation, or the origin of life, opened up the whole of our modern knowledge of the causation of disease through the discoveries of Pasteur, and onward beyond that laid the broad foundations for the wonderful developments of modern surgery which arose from the noble lifework of Lister. Millions of lives have been saved, and untold misery and suffering averted, by practical discoveries which arose from apparently purely philosophical enquiries dealing with theories which might have been dismissed as chimerical.

If the ubiquitous practical man were asked to mention the most magnificent of the discoveries of Pasteur, he would probably name the proof on which modern sanitation is based, that infectious diseases were due to micro-organisms. Brilliant and far-reaching as this discovery is, it will, however, be surpassed in the judgment of later generations by something which the great French savant

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probably did not even realize that he had achieved, and that is the giving of a new basis for the enquiry into the origin of life, by supplying proper limitations and a new starting point.

Pasteur, as the result of years of patient labour, proved with the clearness of a scientific demonstration, that the views of his opponents regarding spontaneous generation were purely mythical. The opposition which met his views can only be compared to the storm which met Darwin and his supporters over evolution, but patiently Pasteur advanced, proving point after point with irresistible experiment and logical conclusion, and in the end he triumphed.

A blind alley in the enquiry as to the origin of life was thus closed for ever, and one with most alluring prospects, which had tempted the minds of philosophers and experimenters for long ages.

Although it was not appreciated, this was a great contribution towards the enquiry. At first sight, the discovery seemed to close the quest for ever, for this path was the only one trodden for centuries by countless enquirers, and it is easier to follow old ways than to find new ones.

It required some years of fallowness, during

which the great practical applications of Pasteur's discoveries monopolized attention, before the main quest could begin to be thought of in the light of Pasteur's investigations.

The great merit of Schäfer's Presidential Address (1912) to the British Association at Dundee lies in this, that it has once more centred the attention of the scientific world upon the main inquiry, and marked it out as a problem that may be solved and one demanding experimental enquiry.

Life probably arose as a result of the operation of causes which may still be at work to-day causing life to arise afresh. Although Pasteur has conclusively proven that life did not originate in certain ways, that does not exclude the view that it arose in other ways. The problem is one that demands thought and experimental work, and is not an exploded chimera. Therein lies the value of Schäfer's contribution to the question, and it is a most refreshing and valuable one.

Before approaching the modern aspects of the problem, it may be of historical interest to enquire what was the position evacuated as a result of Pasteur's researches.

The question of spontaneous generation

had undergone many vicissitudes before Pasteur's time; it had been affirmed or denied by philosopher, naturalist, or poet from age to age.

The great Greek philosopher, Thales, traced the origin of life in water, and Aristotle stated the remarkable paradox that dry bodies engendered animals when they became damp, and moist bodies produced a like effect when they dried.

Van Helmont, a deservedly famous physicist and chemist of the sixteenth century, was a great believer in spontaneous generation, and stated that even mice could be spontaneously generated by the simple device of placing some dirty linen in a receptacle, together with a few grains of wheat or a piece of cheese. The same philosopher's plan for engendering scorpions is naïve and amusing: "Scoop out a hole in a brick. Put into it some sweet basil, crushed. Lay a second brick upon the first so that the hole may be perfectly covered. Expose the two bricks to the sun, and at the end of a few days the smell of the sweet basil, acting as a ferment, will change the herb into real scorpions."

A strange metamorphosis was that announced by an Italian, Buonanni, who found that some rotten timber which he rescued from

the sea, produced worms, which engendered butterflies, and the butterflies, strangest of all, became birds. But it was also from Italy that the first critical experimental observation came : Redi, a poet and physician of that country, clearly demonstrated that larvæ were not engendered spontaneously in decomposing meat, by taking the simple precaution of placing the meat in a wide-mouthed bottle and covering the mouth of the bottle with gauze. Flies attracted by the odour, deposited their eggs on the gauze, and Redi showed that it was from these and not by spontaneous generation that the so-called worms arose. Valisneri, another Italian scientist, gave a similar demonstration for fruit grubs, and thus the basis of our knowledge of the interesting metamorphosis of insects was laid. Later on, that great physiologist, the Abbé Spallanzani, after the advent of the microscope, really quite clearly proved the fallacy of spontaneous generation by experiments as decisive as those of Pasteur a century later. But the age was not receptive, nor was the ground then prepared for the world to understand the importance of the discovery, or take that lead towards the knowledge of the causes of disease which in the hands of Pasteur resulted from his discovery.

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The work of Spallanzani is so remarkably ingenious for the age in which it was performed and has been so overshadowed by later discoveries, that it seems just to quote it briefly.

The experiments of Redi and Valisneri, mentioned above, had refuted the grosser views of spontaneous generation, and it was, strange to say, the discovery of the microscope towards the end of the seventeenth century, which temporarily rehabilitated the theory, at least for microscopic animalculæ. Armed with the new instrument, any one, in a day or two, could easily demonstrate for himself the spontaneous generation of microscopic eels in flour or vinegar, or produce myriads of different and interesting live creatures in rain water kept for a day or two in closed vessels, or in a simple infusion of hay or other organic material. The new wonders of the microscope awakened enthusiasm all over the scientific world, and disputants on both sides fought and argued, for and against, spontaneous generation, and religious feeling was invoked on both sides. To-day, we may be inclined to smile at the simple arguments brought forward as weighty proofs, but it is to be remembered how new all this territory then was, how little orientation any one

possessed, and that the life-histories of these multitudinous forms of microscopic life were not then elementary biology as they are to-day. To explain the appearance of these living organisms, an English cleric, Needham, and the great naturalist, Buffon, evolved the theory that a force, called productive or vegetative force, existed, which was responsible for the production of organized beings. Buffon elaborated the theory that there were certain unchangeable parts common to all living things. These ultimate organic constituents he supposed capable of taking various moulds or shapes which constituted the various living creatures. After death, these ultimate constituent parts were supposed to be set free and become very active. Uniting with one another and with other particles they formed swarms of microscopic creatures such as the microscope revealed, or even produced earthworms and larger fungi.

Needham took putrescible organic matter and enclosed it in vessels which he placed upon hot ashes to destroy any existing animalculæ; yet, later, in these fluids, he found animalculæ which were not observed there in the beginning.

It was in refutation of this work that the Abbé Spallanzani carried out the remarkable

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series of experiments mentioned above. He suspected two defects in Needham's work, just the same as those which Pasteur discovered in the proofs of his opponents a century later, namely, insufficient sterilization by heat, and infection during the experiment with living seed carried from outside, for Needham had only closed his incubation vessels with cork stoppers.

At that early date Spallanzani actually repeated the work in hermetically sealed vessels, and used sterilization by boiling for one hour. He writes, "I used hermetically sealed vessels. I kept them for an hour in boiling water, and after opening and examining their contents after a reasonable interval, I found not the slightest trace of animalculæ, though I had examined with the microscope the infusions from nineteen different vessels." Such work as this accomplished in the middle of the eighteenth century deserves a prominent place for its author in scientific history. The same observer, it may be mentioned, also discovered the antiseptic action of the gastric juice.

Needham's reply was that the prolonged boiling had altered the character of the infusion so that it was unable to engender life. The witty pen of that master of satire,

Voltaire, produced in 1769, a tract in which he laughed to scorn the operations of the English cleric who had engendered eels in the gravy of boiled mutton. He describes as a ridiculous mistake "the unfortunate experiments of Needham so triumphantly refuted by Spallanzani." Elsewhere he wittily remarks, "It is strange that men should deny a Creator and yet attribute to themselves the power of creating eels."

All the wit of Voltaire could not, however, obtain for the work of Spallanzani that credence which it so palpably deserved, and the subject remained a source of philosophical discussion.

The last stage was opened by a paper which was sent to the Académie des Sciences in 1858, by M. Pouchet, a French scientist of high standing. The new departure claimed by Pouchet was that, exercising the greatest care to prevent any error creeping in, he had been able to engender living micro-organisms, plant and animal, in culture media exposed only to *artificial* air or oxygen. The point was that such organisms appeared in a medium absolutely free from atmospheric air, and in which, as a consequence, no germ could possibly have arrived as an air-borne particle.

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This paper attracted universal attention, and stimulated, on the part of Pasteur, four years of incessant labour, crowded with ingenious experiments, all planned towards one common end. He showed that sterilized cultures always became infected when exposed to air; that properly filtered or sterilized air never caused infection; that Alpine air almost free from germs scarcely ever produced a growth of organisms; that city air nearly always produced contamination; and that in absence of added germs from without, culture media remained sterile for years. The sources of error in the work of his opponents were elucidated, and their contrary results explained on such grounds. So, step by step, each logically thought out, Pasteur established his position.

Passing on to the applications of this great demonstration of the impossibility of the spontaneous birth of germs in such culture media, Pasteur himself in the subsequent years of his life discovered the causative germ of several important diseases. Similar labours were also taken up by hundreds of willing hands, and to-day the whole vast science of bacteriology, with its immense applications in modern medicine, surgery and sanitation rests wholly upon this discovery,

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a discovery made, it will be observed, in studying the question of the origin of life. Vast industries concerned in the preparation and preservation of food, and in the scientific fertilization of land, are also based on this unique discovery.

Yet all this by no means settles in the negative the question of the spontaneous origin of life, it only proves clearly that life cannot arise under a particular set of conditions, and so narrows the issue and leads onward to new experimental questions which may even be as fruitful as the old ones.

CHAPTER VIII

HOW LIFE CAME TO EARTH

WHEN it became settled that life did not arise spontaneously on the earth, in the particular way that had been supposed from dead organic matter, the minds of scientists turned towards the explanation of the course by which it had made its advent upon our planet from elsewhere.

One hypothesis which appears to have sprung up spontaneously in many minds,

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with slight variants in each case, is that known as the theory of *cosmozoa* or *pan-spermia*. According to all the many versions, life did not spontaneously arise on the earth, but was carried to it from some other world where it already was existent, either by origin there, or by similar carriage. The various forms of this belief (for it cannot be called more in lack of all experimental evidence) differ as to whether life was coeval with matter and had existed for ever, or whether it was once created on a planet and ever afterwards disseminated. Helmholtz puts the problem clearly when he says, "I cannot contend against one who would regard this hypothesis as highly or wholly improbable. But it appears to me to be a wholly correct scientific procedure, when all our endeavours to produce organisms out of lifeless substance are thwarted, to question whether, after all, life has ever arisen, whether it may not be even as old as matter, and whether its germs, passed from one world to another, may not have developed where they found favourable soil. The true alternative is evident; organic life has either begun to exist at some one time, or has existed from eternity."

Lord Kelvin held similar views before

Helmholtz, and definitely expresses the opinion that, "Dead matter cannot become living without coming under the influence of matter previously living. This seems to me as sure a teaching of science as the law of gravitation."

On the other hand, the great botanist, Nägeli, taught, "If in the physical world all things stand in causal connection with one another, if all phenomena proceed along natural paths, then organisms, which build themselves up from and finally disintegrate into the substances of which inorganic nature consists, must have originated primitively from inorganic compounds. To deny spontaneous generation is to proclaim a miracle."

Not only do the adherents to the several variants of this story of the advent of life upon the earth from space, differ as to whether life has lasted from all time, or was subsequently created, there are many variations as to how it came. Some, such as Kelvin and Helmholtz, regard it as carried by meteorites, or fragments of planets that had borne life when they went to destruction; others, such as Richter, or more recently Arrhenius, postulate an impalpable dust or panspermia scattered through all space and borne from the atmosphere of one planet to that of another. Kelvin may be taken as the ex-

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ponent of the former, and Arrhenius as that of the latter view.

Kelvin, in his address to the British Association at Edinburgh in 1871, put the proposition thus: "When two great masses come into collision in space, it is certain that a large part of each is melted; but it seems also quite certain that in many cases a large quantity of débris must be shot forth in all directions, much of which may have experienced no greater violence than individual pieces of rock experience in a landslip or in blasting by gunpowder. Hence and because we all confidently believe that there are at present, and have been from time immemorial, many worlds of life beside our own, we must regard it as probable in the highest degree that there are countless seed-bearing meteoric stones moving about in space. If at the present instant no life existed upon this earth, one such stone falling upon it might, by what we blindly call *natural* causes, lead to its becoming covered with vegetation."

The view of Arrhenius is a more modern variation; he proceeds from the known facts of bacteriology, that the minutest germs of life float about in the air, many of them ultra-microscopic in magnitude. These minutest germs of living matter may be carried

to the upper strata of an atmosphere, and here come under the influence of radiant energy of various forms, as minute dust particles may in the *aurora borealis*, for example. It has been shown that there is a pressure of the light waves upon such particles, which is capable of giving them a translatory velocity in a vacuum, similar to that of the vanes of Crookes' radiometer in radiant light or heat. It is only necessary to assume small enough dimensions of the germ particles to achieve enormous velocities. Arrhenius calculates, that if living germs were carried through the ether by such radiant forms of energy, the time of transit from our earth to Mars would only be twenty days, and from our solar system to the nearest stellar system about nine thousand years.

These stellar and interstellar hypotheses as to the advent of life upon our earth cannot be better criticized than in the words used by Professor Schäfer in his presidential address to the British Association, Dundee, 1912 :—" But the acceptance of such theories of the arrival of life on the earth does not bring us any nearer to a conception of its actual mode of origin ; on the contrary, it merely serves to banish the investigation of the question to some conveniently inaccessible

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corner of the universe, and leaves us in the unsatisfactory position of affirming not only that we have no knowledge as to the mode of origin of life—which is unfortunately true—but that we never can acquire such knowledge, which, it is to be hoped, is not true. Knowing what we know, and believing what we believe, as to the part played by evolution in the development of terrestrial matter, we are, I think (without denying the possibility of the existence of life in other parts of the universe), justified in regarding these cosmic theories as inherently improbable—at least in comparison with the solution of the problem, which the evolutionary hypothesis offers.”

It has been seen in following the evolutionary process, step by step, in the preceding chapters, that even in the inorganic world gigantic molecules can be built up. And that as molecular complexity increases, and the firmness of chemical union in the constituent parts decreases, a delicate mobile balance becomes established, easily destroyed but, within the limits of its stability, capable of oscillatory energy changes.

Many of the properties of the molecules of these inorganic colloids approximate to those of the organic colloids found in living structures.

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The whole living world depends upon the building up of the energy of the sunlight into the chemical energy of these organic colloids which constitute living structures. The energy-transformer is the green cell of the plant, and, directly or indirectly, the energy of all that lives, in the present stage of evolution, arises from this one source transmuted by this one transformer. In the vegetable world itself, those parts of the plant which are not green possess no power of building up energy from inorganic sources. Such parts of the plant obtain organic substances as a source of energy from the green parts, and the colloids of such parts transform these organic compounds into others, use up their energy to supply power for their own processes, grow in size by transmuting the supply into more colloid, or form reserve depots intended primarily for their own use, or that of their next generation, in the shape of seeds, fruits, roots and tubers. The bodies of the plants, including their reserves, are eaten by animals, and are broken up by the digestive juices into soluble compounds which can again be built up into colloids by the already existing colloids of the living cells of the animal. Part of the animal's food thus provided is oxidized and decomposed back

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into inorganic substances giving out on the way its energy for the life processes of the animal; another part is built into reserve chemical energy just as in the plant. There are also whole classes of plants which derive their energy just like animals, by living on the chemical energy of other plants, or upon animals. Such are the fungi and the bacteria which produce disease when they invade the bodies of plants or animals, or those which act as purifiers by decomposing dead plant or animal remains, reducing them to inorganic constituents, and so completing the natural cycle. In the process, energy is set free and intermediately used by the bacteria flourishing upon the dead matter. With the exception of certain supplies of energy utilized from winds and tides and waterfalls, all the energy used by man for driving human industries and concerns comes from past or present sources of this kind, such as wood, coal, petrol, and spirit which represent the energy of the sunlight of past ages, either immediate or remote.

All the conveniences and luxuries of modern civilization are dependent upon energy derived from sunlight through the agency of the transformer contained in the green plant cell.

Now the green colouring matter, which acts

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as an intermediary between the colloids of the green cell and the sunlight, is itself an exceedingly complicated colloid resembling, in many properties, and related to, the colouring matter of the blood of higher animals. Without this green colouring matter, called chlorophyll, the other colloids of the green cell could not themselves transmute the light energy into chemical energy for the maintenance of the organic world.

When a plant is allowed to develop in darkness, its leaves are colourless, or etiolated, as it is termed, no pigment is developed, and such a plant can build up no fresh organic material, and is limited to that which it already possesses. It has been allowed no source of energy in the sunlight, and develops no mechanism to transmute it. It lives and develops for a time on the reserve of organic material which it possesses, and then sickens and dies. But if, before this happens, and while it is still colourless, it is exposed to light, then the organic colloids in its parts which would naturally have been green, acted upon by the sunlight undergo a series of energy transformations, as a result of which the body called chlorophyll is developed. This begins to absorb the light energy, and takes into its molecule carbon-

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dioxide and water, so that these constitute parts of the cell-colloid ; oxygen is then split off and the carbon, hydrogen and a less amount of oxygen, are built up into those organic, energy-containing bodies described in a previous chapter. These bodies are built up as part of the colloidal complex of the cell, until an excess of them is present, when they separate out as reserve carbohydrates, fats and proteins. From time to time these are dissolved out and transported in the plant sap to other parts of the plant, to supply energy and serve as materials for growth, and the plant in all its parts goes on increasing and growing. This organic growth afterwards serves as food for the rest of the world of living organisms.

The green colouring matter wrested from its connection with the living colloid of the cell in which it occurs is almost devoid of power to produce these changes. It may be readily dissolved out by solvents such as alcohol, chloroform or benzene, then suspended in water, and exposed to sunlight in presence of those inorganic constituents which in its normal situation it transmutes into organic matter. But under such conditions an infinitesimal amount¹ only of one of the first products of organic synthesis is obtained

and the process soon comes automatically to an end.

But when the cell colloid, and chlorophyll, and the inorganic constituents to be acted upon are built up into one chemical whole, and then the sunlight plays upon this complex colloid, molecular vibrations and energy exchanges are initiated which cause up-building of organic matter and transformation from one organic substance to another. Similarly, in those other cells of plants and animals which possess no green transformer, it is only when the organic matter (built up elsewhere in the green cells and transported to the colourless parts) has become an intrinsic part of the colloidal mass of the new cell, that it can be acted upon and made to part with its energy, or used to form living matter. A molecule of carbohydrate, or fat, or protein, can only form an integral part of living matter, or yield energy to living matter, after it has been assimilated into the colloidal mechanism of the cell and chemically constructed into its mass.

The substance chlorophyll is itself far too complex to arise as a first step from inorganic matter in the absence of life, yet as the present life-builder of the world, it gives a clue as to what ought to be sought for in

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all experimental work designed to discover a bridge over the interval between the inorganic and the organic. The modern problem of spontaneous generation dawns upon us from these considerations.

If a mental picture be conjured up of a world in which there is as yet no life, but where conditions are suitable for life to appear, it is evident that a spontaneous production of such a thing as even a bacterium or other unicellular organism, would by no means solve the problem, the new-born cell would have no organic pabulum and must perish. The production of anything so complex as chlorophyll at such a stage is unthinkable to any one acquainted with the subtle continuity of all nature. In such a world inorganic colloids must first develop, and in time one of these must begin to evolve, not a living cell, not anything so complex as a micro-coccus or a bacillus, not even a complex protein, carbohydrate, or fat, but some quite simple form of organic molecule, holding a higher store of chemical energy than the simple inorganic bodies from which it was formed. To carry out such a function the inorganic colloid must possess the property of transforming sunlight, or some other form of radiant energy, into chemical energy.

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Later, such simple organic compounds, by the agency of the same or some other colloid, and with a supply of external energy, would begin to condense and form more complex organic molecules, and finally complexes of inorganic and organic matter would come into existence as crystallo-colloids. In this way without any hiatus life would be led up to, and inaugurated.

The search for such an inorganic transformer is not without a hopeful outlook. It is already known that the element selenium and other inorganic bodies, are affected by light. The whole field of photography, as well as many researches upon chemical actions induced or hastened by light, encourages the researchers who have already started on this quest. It has been claimed by one observer (Bach), that an organic compound termed formaldehyde, usually regarded by botanists as the first step in the synthesis of sugars by the green plant, is formed artificially when in the presence of sunlight, carbon-dioxide is passed through a solution of a salt of uranium. Traces of this organic body are also stated by Fenton to be produced when metallic magnesium is immersed in water that has been saturated with carbon-dioxide.

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Much patient work may be required before the exact constituents in the just proportions are experimentally found out, as well as the proper conditions of temperature and exposure to light or other form of radiant energy, to produce more complex organic bodies, but it is evident that we are here face to face with a practical experimental problem, and not confronted with the impossible, or doomed to indulge only in philosophical speculation without being able to test our results.

The problem we are attacking now is that of how organic matter arose endowed with its own peculiar energy-forms in a world where there was no previous trace—not merely of living matter—but of dead organic matter. Such a lifeless world it is barely possible for us as inhabitants of this green earth covered with teeming energetic life to realize or postulate to ourselves.

Yet, in this lifeless inorganic world somewhere about the time when life, on account of temperature conditions, first became possible, living creatures promptly (in the geological sense) became present, as the record of the older sedimentary rocks teaches us to-day.

The degree of chemical complexity capable of existing in the materials found on the

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earth is definitely and sharply fixed by temperature. At a white heat such as exists in the sun's atmosphere, we have seen that only elements can exist, and many of these are decomposed into proto-elements. At a somewhat lower temperature binary compounds, such as the oxides, can remain in equilibrium, in incomplete combination, becoming more and more complete as the temperature falls, and as soon as their existence becomes possible these oxides do exist. Lower still in the scale of temperature, saline compounds, such as chlorides of the alkalis, and mutually neutralized acidic and basic oxides combined together, can stand the heat. Such bodies as the carbonates of calcium and magnesium can now be present in an incomplete state of combination, partially as oxide and partially as carbonate, in labile balance as the temperature fluctuates up or down, and the pressure of carbon dioxide in the atmosphere changes. Whenever the environmental conditions make their presence possible, these more complex forms must promptly make their appearance by chemical law.

But it is only at a very much lower temperature that compounds at all complicated in chemical structure can exist in equilibrium,

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and for those compounds of many hundreds of atoms which are characteristic of life, the range is narrowly limited.

Thus, all the life of the planet would be destroyed at a temperature which we may place for absolutely inclusive purposes at 56°C . At about ten degrees below this temperature all birds and all mammals would cease to exist. The other species would have perished long before, the vast bulk perishing at 25° to 80°C ., which is below human blood heat. Even those highly organized ferments, called enzymes, which, when separated from the living cell that bore them, still bear half-impressed upon them certain living properties—all these suffer rapid deterioration in all known cases at 50°C ., and at 60° to 70°C . they are rapidly destroyed.

Since sedimentary rocks would begin to be deposited soon after the surface temperature of the earth had fallen below the temperature of boiling water, viz., 100°C ., the early appearance of fossil remains in the older sedimentary rocks, when due allowance has been made for the geological time necessary for the earth's surface to cool from boiling point to the life-temperature, demonstrates the important point that as soon as tempera-

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ture allowed sufficient complexity of chemical structure for life to be borne upon the earth, then life appeared.

This note cannot be too strongly sounded that as matter is allowed capacity for assuming complex forms those complex forms appear. As soon as oxides can be there, oxides appear; when temperature admits of carbonates, then carbonates are forthwith formed. These are experiments which any chemist can to-day repeat in a crucible. And on a cooling planet, as soon as temperature will admit the presence of life, then life appears as the evidence of geology shows us. But the latter cannot as yet be repeated by the chemist because the conditions of chemical complexity are too delicate, and the colloids begin to show their characteristic slowness of reaction and delicacy of balance.

Next in order of development prior to life, inorganic colloids begin to appear in solution, or suspension, in the waters of the cooling globe, alumina and silica deposited in colloidal form are seen in many sedimentary rocks. Single molecules existing in solution, and capable of forming colloids, with alterations in temperature, and in chemical reaction of the environment, begin to form complexes, or solution aggregates, in which the unit of

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chemical structure passes from the atom to the molecule.

Accompanying these structural changes, the energy types and phases inhabiting the unit of structure also vary. The rates of vibration or of phasic activity in the colloidal aggregates become slower than in the simplest molecules of the crystalloids. All that has been described in the previous chapter as characteristic of colloids, viz., slowness of reaction, meta-stable equilibrium, delicacy of union, and increased reactivity of specific type, becomes present in the forms of matter now capable of existing in equilibrium with the environment. As the complexity of structure increases, the nature of the equilibrium in the colloidal aggregates approaches more and more towards that labile, easily destroyed, but also more readily constructive condition which has been described as characteristic of life.

It may then be summed up as a general law universal in its application to all matter, although varying in intensity in different types of matter, and holding throughout all space as generally as the law of gravitation—a law which might be called the *Law of Complexity*—that matter so far as its energy environment will permit, tends to assume more

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and more complex forms in labile equilibrium. Atoms, molecules, colloids, and living organisms, arise as the result of the operations of this law, and in the higher regions of complexity it induces organic evolution and all the many thousands of living forms. At still higher levels, it forms the basis of social evolution and leads to that intellectual development in individual and community which surmounts the whole and is ever building upwards.

In this manner we can conceive that the hiatus between non-living and living things can be bridged over, and there awakens in our minds the conception of a kind of spontaneous generation of a different order from the old. The territory of this spontaneous production of life lies not at the level of bacteria, or animalculæ, springing forth into life in dead organic matter, but at a level of life lying deeper than anything the microscope can reveal, and possessing a lower unit than the living cell, as we form our concept of it from the tissues of higher animals and plants.

In the future, the stage at which colloids begin to be able to deal with external energy forms, such as light, and build up in chemical complexity, will yield a new unit of life opening a vista of possibilities as magnificent as that which, the establishment of the cell

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as a unit gave, with the development of the microscope, about a century ago.

It was no fortuitous combination of chances, and no cosmic dust, which brought life to the womb of our ancient mother earth in the far distant Palæozoic ages, but a well-regulated orderly development, which comes to every mother earth in the Universe in the maturity of her creation when the conditions arrive within the suitable limits.

Given the presence of matter and energy forms under the proper conditions, life must come inevitably, just as, given the proper conditions of energy and complexity of matter in the fertilized ovum, one change after another must introduce itself and give place to another, and spin along in kaleidoscopic sequence till the mature embryo appears, and this in turn must pass through the phases of growth, maturity, reproduction, decay, and death.

If this view be the true one, there must exist a whole world of living creatures which the microscope has never shown us leading up to the bacteria and the protozoa. The brink of life lies not at the production of protozoa and bacteria, which are highly developed inhabitants of our world, but away down amongst the colloids, and the

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beginning of life was not a fortuitous event occurring millions of years ago and never again repeated, but one which in its primordial stages keeps on repeating itself all the time and in our generation. So that, if all intelligent creatures were by some holocaust destroyed, up out of the depths in process of millions of years intelligent beings would once more emerge.

In this process of chemical evolution up to the stage which we at the present day regard as living, it is to be observed that as the non-living colloid becomes more and more complex and accordingly more and more labile, it at the same time must become more and more susceptible to the influence of external stimulation by different forms of energy. .

This means that it must, under such conditions that it can remain in equilibrium without decomposition, become more and more a machine for uptake and utilization of energy. The fact that the present basis of the system of living creatures in the world is light energy, leads to the view that at a certain stage in the development of colloids, probably long before the appearance of chlorophyll, the colloids began to be affected by the light, and acquired the property of

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retaining and utilizing light energy for the further development of structure, or, in other words, synthesis of more complex colloids.

A second point of importance is the gradual increase in time periods arising as development progressed. The simpler a chemical reaction is, as a general rule, the more instantaneous it is; with increasing complexity, the time phases grow longer.

The early stages in development up towards life would hence be rushed through rapidly, and be easily and constantly reproducible. As complexity increased so would the time grow longer for any chemical evolution. More especially the time necessary to reach any higher stage of organization *de novo* would be immensely increased on account of instability and tendency to break down again, as different and more delicately balanced stages were passed. There would here come in the tendency of external conditions to stop the process at certain levels, and the steeper slopes of development would only be infrequently ascended, until the establishment of something resembling a species, but still short of life arose by a run over into a stable condition in one case out of many millions. This species of highly organized colloid could then more easily sustain and reproduce itself by

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inoculation into suitable material, and growth there, than by starting afresh from simpler bodies. It would form a fixed starting point for further development, just as at the stage of living things each new species would form a fresh point of departure. A labile equilibrium, stable and capable of reproducing itself with suitable conditions of material and environment of energy, would so be set up, but requiring a long period of time for re-development if once the type were lost.

The only observer who has claimed to have obtained experimentally the evolution of living organisms from inorganic sources is Dr. Charlton Bastian, who was earlier an opponent of the views of Pasteur, and a controversialist with Huxley in regard to spontaneous evolution. Bastian claims that when either of two mixtures of inorganic constituents, which he describes in detail, is sterilized at a temperature of 110° to 115° C., in a hermetically sealed tube, and then allowed to remain for a considerable period of time, varying from three to six months, micro-organisms of many types appear which were not originally present, such as micro-cocci, torulæ, vibriones, and moulds. The solutions used were as follows:—(a) sodium silicate, ammonium phosphate, dilute phosphoric acid,

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in distilled water, and (b) sodium silicate and per-nitrate of iron, also in distilled water. The latter solution gave more abundant organisms according to the author. The exact concentrations used may be found in his work as quoted in the bibliography at the end of the volume.

No results are said to be obtained in a short interval such as one or two weeks, and this is used as evidence to prove that the results found in other tubes kept longer are genuine and not fortuitous from occasional infection. The proofs relied upon by Bastian in favour of the products he obtains being really living organisms, are (1) the microscopic appearances, (2) the staining properties to micro-chemical reagents, and (3) the fact that, when the structures are sown into proper nutrient materials, then they reproduce themselves just as micro-organisms would reproduce themselves when sown into a nutrient medium. Bastian draws a careful and quite legitimate distinction between a nutrient medium containing material capable of nourishing and causing to multiply a micro-organism already there, and a medium capable of causing organisms to engender.

An important point is that Bastian found that generation occurred better and the

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organisms were more plentiful when the sealed tubes were exposed during these months to diffuse daylight. This appears to have been an incidental experience, but if these results of Bastian are real, it is obvious that some such form of energy must be made available in order that organic may arise from inorganic matter. Some batches of tubes were indeed found to engender more imperfectly in an incubator, but this incubator was heated by an incandescent electric light placed within it so that a source of radiant energy was available here also.

It is also to be noted that the composition of the two fluids for which success is claimed, happens to be just that which will throw the silicic acid, or mixture of silicic acid and ferric oxide, into the condition of a labile colloid most favourable for energy capture.

In the first solution mentioned above, the sodium silicate on account of its alkalinity is non-colloidal, but to this is added a small amount of phosphoric acid in presence of a small amount of ammonium phosphate. This addition will just give that faint acidity which will make the colloidal silicic acid appear, without, on the other hand, being so acid as to throw the colloid out of solution. In the case of the second solution, the ferric nitrate

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solution is acid, and when this is added to the alkaline sodium silicate, the tendency is to form a mixture of two colloids, viz., colloidal silicic acid, and colloidal ferric hydrate. From this point of view it is of interest to note that the optimal condition at which the experimenter is instructed to aim by Bastian, is that at which a small amount of precipitate appears some time after sterilizing. This empirical direction simply means, to the chemist, that the point is to be aimed at where colloid is formed but not precipitated.

These experiments as to evolution of organisms from inorganic solutions have not been repeated by other observers but such test experiments and others upon similar lines, are now in progress.

The conditions in these later experiments of Bastian are essentially different from those of his earlier work, a fact which does not appear to have been fully realized by those who have adversely criticized them without attempting their repetition.

There is one thought which occurs to the mind, and that is, that what might have been expected would have been simple organic bodies in solution rather than micro-organisms. In science the unexpected has, however, a remarkable way of happening,

and it may be found that within a period of three to six months, in presence of suitable energy sources and a suitable transformer of colloidal character for transforming such energy, the level of micro-organisms may possibly be attainable.

CHAPTER IX

THE LIVING ORGANISM AT WORK

. IN the preceding chapters a continuous process of evolution has been traced out from the electron to the atom, from the atom to the molecule, from the molecule to the colloid, and so to the confines of the organic world.

In the territory of living organisms, the continuity remains unbroken for all living creatures are made up of structural units. The unit of the biologist is the living cell. All living creatures are composed of one or more of these units, called living cells, and the biologist divides his realm into two great divisions, that of the unicellular organisms (protozoa and protophytes), and that of the multicellular organisms (metazoa and metaphytes).

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The living cell consists of a combination of colloids existing in dynamic equilibrium with one another, and carrying on an exchange of energy phenomena peculiar to living matter with one another and with their environment. The study of these energy changes forms the province of the physiologist and bio-chemist.

The character of the energy reactions varies in a very specific way from one type of cell to another, dependently upon minute and delicate differences in colloidal structure in the different kinds of cell. It has been seen that as structure became more complex, energy exchanges also varied, and it is accordingly only to be expected that the acme of this differentiation should occur at the most complex range of all in the living cells of higher animals. It is upon this that the vast number of varieties of living types depends, and here arises that individuality and fine differentiation which is found in higher animals and in man.

The body of one of the higher animals, or man, consists of an enormous assemblage, or community, of many millions of millions of such living units far outnumbering the total population of human individuals on the earth, and this vast community of living cells

which together constitute a living man or woman, are, in a state of health, so co-ordinated and regulated as to excel, in goodness of government and co-adaptation to one another's wants, any social system which has ever regulated a body corporate in human history. There is just as much division of labour and mutual assistance and governance as in a state or vast empire, and, moreover, there are scarcely any of the defects of a bad government in the affairs of men in a social community, which may not find their parallel in the organic happenings in a single human body when invaded by disease. Similar types of cell are aggregated together into formations, called tissues, designed for serving some common office of the body, and at times two or three tissues are blended together to form what is termed an organ for carrying out some special task. The stomach may be taken as an example of such an organ. Internally it possesses a layer in which are millions of cells formed into little tube-like glands, which secrete a digestive fluid and pour it out by millions of minute ducts or pores upon the food contained in the cavity of the stomach. Outside this glandular layer there is a series of layers of contractile substance called muscle, beautifully designed

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and arranged, and the degree of contraction of the constituent cells of this muscular layer enables the stomach to adapt itself to the amount of food within, and keep up a certain pressure upon its contents. As the stomach expands when food enters, the walls become thinner by the elongation of the muscular cells, and as the food is passed onwards towards the intestine the muscle cells shorten again, so as always to keep the stomach full at different sizes. Thus a cavity is obtained with an adaptation to the amount of its contents, much more perfect than would be given by a rubber bag which, of inanimate receptacles, more nearly resembles it than any other. In addition to this steady tone of the stomach walls, increased contractions occur in regular series with a slow rhythm, and these serve the purpose of mixing up the food and the digestive secretion. Further, when digestion has proceeded far enough, and the condition of the contents of the intestine warrant it, these movements serve the purpose of passing the food onwards into the lower part of the alimentary tube. Similar instances of adaptation of structure and function might be multiplied by the thousand all over the body. Such delicate adaptation, which in some cases is demon-

strable to the unaided eye, and in other cases only when the aid of the microscope is invoked, passes even beyond visible structure, onward into the region of chemical structure, for it is found that nearly every tissue (or assemblage of similar cells) of the body secretes certain chemical substances into the general blood stream which are carried around to another situation in the body where there is a different assemblage of another kind of cell to be benefited by this internal secretion, as it is called. So close is this chemical sympathy, and so absolutely necessary are the chemical substances so formed, which have been called *hormones*, or excitants, that the loss of one of them in many well-known instances leads to such changes that the death of the whole animal results.

This kind of biological civilization, or social economy, within the whole animal, and the interdependence of all parts upon a wide commerce of exchange, is the most fundamental thing in the physiology of the higher animal. Apart from gross lesions due to injury, it may be said that all the problems of disease, and all the causes of death, depend upon the upset of the delicate balance of such chemical exchanges between the various types of cells composing the body.

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The mischief may arise in two fundamental ways, (1) perversion of the functions of some assemblage of cells from within so that the chemical products yielded are different, and so become poisonous to these or some other set of cells ; or (2) invasion by disease organisms or parasites which multiply and produce foreign chemical substances. These poisonous substances irritate and finally kill the normal cells, either locally where they are situated, or by discharge of soluble chemical poisons into the blood stream, which are then carried away all over the body to other tissues, and incapacitate, or destroy their living cells. The organisms of disease do not injure or kill simply by their presence, they do so by chemical poisons which play in upon the delicate balance of the colloids of the living cells of the body. The degenerations and obvious effects of disease, such as are obvious to the unaided eye or by the help of the microscope, are practically all produced by such poisonous chemical products.

Both in their outward form as viewed under the microscope, in size, and in grosser internal structure, as well as in specific chemical structure, living cells differ enormously. Thus, amongst unicellular organisms, there are

exceedingly minute forms, some quite harmless and even beneficial, and others the exciting causes of more than half the ills that flesh is heir to. These tiny organisms, sometimes form practically structureless colloidal globules, as far as the highest resolving powers of the microscope reach, which are known as *micro-cocci*. Yet each one of these minute dots forms a little microcosm, made up in each species of micro-coccus of a highly specific grouping of complex colloidal molecules, with a commerce of chemical exchanges entirely its own, and unlike that of any of the other species of micro-cocci. So that in the majority of cases it is by its effects and bio-chemical reactions alone that a micro-coccus can be distinguished from others microscopically indistinguishable from it. The advance of modern bacteriology has made it absolutely indispensable to the bacteriologist to possess a highly special training in bio-chemistry, and micro-organisms are nowadays distinguished far more by the reactions which they induce in culture media, or in the fluids taken from man or another mammal, or by the specific changes which they produce in the body as a whole, than by examination with the microscope. The microscope, as a rule, gives the bacteriologist only

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a first rough orientation and places the organism in a group; its identification then follows from its chemical behaviour, and in all chemistry there are no reactions so delicate and specific as those induced by these minutest of living organisms.

Two micro-organisms so closely similar that a skilled bacteriologist cannot distinguish them by examination with the highest powers of the microscope, when they invade the body of man, or are inoculated into an animal, produce two diseases absolutely specific and quite different from each other. The physician can diagnose the two diseases with the greatest ease, and in all cases of infection the one germ produces its own disease, and the other quite as definitely its special disease with definite symptoms. Each micro-organism produces its own specific set of chemical poisons called *toxins*, and these toxins have special affinities for certain of the tissue cells, on account of adaptation of structure of the colloid molecule of the toxin to the colloids of the cells of the affected tissue. In fact, these two fit together almost like a highly complex lock and key, while other colloids of other tissue cells devoid of such specific adaptation are left entirely unaffected. This accounts for the favourite

sites of growth of different micro-organisms in the body; for the chemical constitution of one kind of cell, such as a cell in the intestine say, suits one organism, while another finds its best pabulum in the lung, another in muscle, and another in the cavity of a joint.

• By means of the chemical sympathy above mentioned, while one site may best suit the growth of an organism, quite another site and type of cell may be most adapted to react with its poison, or toxin, so the obvious and dangerous results of the disease may appear at points remote from the invading army. Thus, the organism responsible for the production of diphtheria, for example, grows in a restricted area of the tonsils and throat, small compared with the bulk of the body. Apart from occasional difficulties of a mechanical nature connected with respiration, the local effects are not dangerous. But the minute organisms produce a soluble chemical substance, the diphtheria toxin, which is of the same order of deadliness as snake venom. This is discharged into the blood stream, and is absorbed chiefly by two types of body-cells, on account of the above-mentioned chemical adaptation of its molecule to their particular colloids. These two tissues happen to be master-tissues of

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the body, the work of which cannot even temporarily be interfered with, namely, the heart muscle, and certain important nerve-centres controlling respiration and heart-beat. As the poison from the diphtheria organisms locks into the labile oscillating colloid aggregates of these rhythmically working cells, their character alters.

It is as if a strange key had become jammed in a beautifully constructed lock, so that its own key could no longer shoot the bolt of the lock to and fro. When the amount of poison absorbed passes a certain limit, the heart becomes irregular or the respiration troubled, and soon there too often happens the sudden death from heart collapse, or, if that be prevented, the serious paralyses of other nerve centres seen later in severe cases of the disease.

Strange to say, it is just the violently poisonous nature of the toxin of diphtheria which has enabled modern biological science to supply a remarkable bio-chemical specific for its treatment, such as cannot be produced for a disease with a toxin of low poisonous power, as, for example, tuberculosis. The procedure illustrates so well the delicate relationships and balance of the colloids of cells, and the natural mode of limitation of

diseases, that a brief outline of it may prove interesting. When an alien organism has invaded an animal and commenced to form poisons from the nutrition supplied by its host, there is always a reaction induced against the infection. There are two modes of combat, one by means of a vast number of free-living cells in the blood-stream of the host, which engulf and digest the bodies of the attacking organism. In so digesting these organisms, these disease-resisting cells (called leucocytes) produce substances which have the exactly opposite effects to the toxins, and are called anti-bodies or antitoxins. Secondly, other cells in the body, while they do not engulf and swallow the foreign organism join in producing anti-bodies, which weaken and kill the invading organisms, and also combine with and neutralize the toxins which the organisms have produced, and by saturating these prevent them attacking the tissue cells.

It is such a struggle as this which sets a date to the duration of all the acute infectious diseases, and the more poisonous the products of the invading organism, so much the sharper and shorter the struggle. • It is the production of the anti-bodies in addition to chemical changes induced in the body cells

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which confer the more or less perfect after-immunity from any second attack of the disease. As a rule, the more acute and poisonous a disease product the greater the after-immunity.

On this knowledge is based both the anti-toxic and vaccine treatments of disease so successful in modern days, as well as many of the new methods for the bacteriological diagnosis of disease forms.

In the antitoxic treatment of disease, so conspicuously successful in diphtheria, a vicarious animal is called in, one being chosen which is itself susceptible to the organism, but at the same time possesses a fairly high resisting power. Such an animal in the case of diphtheria is found in the horse. Next the organism of the disease is cultivated on a fairly large scale in a nutrient broth or fluid culture medium. After some days, the organisms are separated by filtration through a fine filter such as a Chamberland or Berkefeld candle, so yielding a fluid in which the toxins of the disease are dissolved. This filtrate is then injected in graduated doses into the vicarious animal. The cells of this animal set up a reaction, destroy the poison, and manufacture, in excess, anti-toxins. The process is continued

until the fluid part of the blood of the animal is as highly charged as possible with the antitoxin, and the animal itself is now immune to the disease. Incidentally, it may be mentioned that this is what is achieved in the body of man himself (or highly valuable animals) by preventive vaccination or inoculation, as in smallpox vaccination.

Now, returning to antitoxic treatment, small quantities of the blood of such an immunized animal when drawn off contain dissolved in the fluid part of the blood (or serum) chemical substances capable of neutralizing the poisonous toxins, and these are the antitoxins, or natural antidotes to the disease.

Such is anti-diphtheritic serum or diphtheria antitoxin. It produces its wonderful effect by yielding early in the disease a supply of just that material which the body is struggling to make for itself, and this auxiliary supply both protects the vulnerable tissues, and being absorbed by the invading organisms, weakens them at an early stage when as yet they are not very abundant and so renders them both less productive and also an easier prey to the natural forces at work.

It is now readily seen why the anti-toxic

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treatment is more adapted for dealing with small amounts of a virulent poison than with larger amounts of a weaker poison, for the excess of vicarious antidote cannot be raised to a high level. Also the less virulent poison of a chronic infectious disease, such as tuberculosis, does not by a violent reaction of the body lead to a heavy production of anti-toxin, and the anti-toxin produced in response is also not such a deadly negative, so far as the invading disease organism is concerned.

With such a heavy handicap to fight against, it is obvious that tuberculin treatment, which, while differing in detail, is conceived on the same lines, can only be successful when applied very early, and when there is no very massive infection to contend against. This is the reason why it has found more success in joint cases where the infection is more limited.

Vaccine treatment differs from anti-toxic treatment in that the vicarious animal is dispensed with, and a culture of the organisms of the disease, made if possible from a strain obtained from the actual patient, is first sterilized and then injected. Conspicuous success has followed the vaccine treatment in certain chronically recurring skin affections,

such as acne, and feruncle (or boils), more especially when cultures have been carefully made from the strain of organism in the patient's own body which is actually causing the disease. This has now become a standard treatment in such diseases.

• In diagnosis also these chemical reactions have yielded great aid to practical medicine, and to us here these diagnostic reactions are of high interest because of the beautiful examples they provide of the delicate structures and reactions which have become evolved as a result of the increasing complexity of design in living organisms. One example must suffice as a sample of the whole. A certain percentage of cases of enteric fever are very difficult to diagnose on account of absence or variation of important clinical symptoms characteristic of typical cases; but a very simple bio-chemical test here furnishes a valuable indication. Enteric fever is caused by a motile microscopic bacillus (the *Bacillus typhosus*), which moves about by means of long, fine, whip-like processes at one end of a short stout, rod-like body. This organism can readily be cultivated artificially in nutrient broth and other artificial media, and when a drop of this nutrient fluid, diluted with a dilute solution of salt of the proper

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strength, is placed under a microscope, the organisms are to be seen propelling themselves about actively in all directions, and fairly uniformly distributed. The same effect is seen if the enteric culture be mixed with a small amount of the fluid part of the blood of a normal person (diluted normal serum). But if the serum of a person suffering from enteric fever be taken, a minute drop being all that is necessary, and equally diluted, then on mixing this with the enteric culture as before, and examining under the microscope a most remarkable result is seen. All the enteric organisms, which before were swimming about freely, in about ten to fifteen minutes are found to have gathered themselves together, into clumps of half-a-dozen to a score, or, as it is termed, have agglutinated. The flagellæ are still moving but only to preserve the clumped arrangements. If bacteria possessed minds it would almost seem as if the situation were being debated at meetings, much as war news might be discussed in a distracted community. The chemical basis of the phenomenon is that in the blood of the patient afflicted with the enteric fever, minute traces of an anti-body to the enteric organism have been produced in an amount far too slight

to demonstrate by any ordinary chemical reaction known to us, but easily demonstrable by this bio-chemical test. This inimical substance has been suddenly presented to the enteric organisms cultivated artificially outside, and this agglutination is the result. The agglutination is probably due to alterations in what is called surface tension at the interface between the organism and the fluid in which it is immersed. The reaction is so delicate and specific that it will occur even when the enteric serum is diluted two-hundred-fold in a typical case. First discovered for the enteric organism, this property of agglutination has since been extended to many others, and is now used as a routine method of settling the identity of suspected organisms, as well as for diagnosing the nature of individual cases of disease. Nearly allied organisms cause mutual agglutination, each for the other, in fluids in which cultivations have been previously made, and the degree of dilution at which agglutination occurs indicates the closeness of relationship in a group, or complete identity. Organisms more remote have no effect upon one another. It is thus seen, even at the level of bacteria, how complex and finely balanced the structure of the colloids has become. It will presently

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be shown how these balanced relationships and sympathetic chemical affinities of colloids become intensified and individualized as the complex cell colonies come into co-existence in the same organic whole, or body of the higher animal.

It must not be supposed that all bacteria exist only as parasites within the bodies of man and the higher animals; many perform indispensable functions in restoring dead, organic matter back to inorganic forms, others, more directly useful still, attach themselves to the growing rootlets of the plants which supply our food, and enable these to take up nitrogenous nutrient matter from the soil. Without such common life or commensal existence, the growth of some of our most valuable food plants would be impossible.

In the bacteria, there are large groups distinguished by the form of the organism, such as the rounded micro-cocci, which are subdivided again according to whether they grow singly, or in chains, or groups, into mono-cocci, diplo-cocci, strepto-cocci, and staphylo-cocci. Similarly, in the rod-like forms of bacteria called bacilli, in which the relative length and breadth, straightness or curvature, presence or absence of motile

structures, staining reactions, and bio-chemical reactions, again give many divisions, which need not here be named.

The micro-organisms hitherto dealt with are all usually referred to a subdivision of the fungi amongst the plants (Schizomycetes). There are in addition to these, many thousands of types of botanical micro-organisms belonging to other families, some parasitical, and others chlorophyllaceous, and building up their own organic materials.

There are also many thousands of types well known, in addition to many as yet unstudied and unclassified, of unicellular or protozoan animals, found chiefly in fresh or marine water, in the fluids of soil, in higher plants or animals, or in decaying organic organisms or fluids.

Many of these protozoa occurring free in the blood or body-fluids or enclosed in the living cells of plants or animals, are the now familiar causes of many important diseases. Such animal parasites, unicellular, and of microscopic dimensions, seem especially to take a large part in the causation of tropical diseases, such as malaria and sleeping sickness. It is now known that several of these protozoan parasites are borne from one host to another by insects, and possess a

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double life-cycle, in part consummated in man, and in part in the insect.

One of the most fatal of diseases, syphilis, a most potent factor in racial degeneration, which, unfortunately, flourishes in all climates, has recently been shown to be a protozoan disease carried by a minute animal organism called, from its spirally arranged or twisted form, a spirochæte.

Most classical descriptions of a typical, living cell are based on that particular class of animal cell called an *amœboid* cell, although the word cell itself is derived from botany. In plant tissues where growth is fairly rapid, the cells lie close alongside of one another, separated by outer membranes or cell walls, so that the appearance comes to resemble the cells of a honeycomb.

The word cell, later came to be extended to all living units as shown by the microscope, although the wide and free exchanges of cells with one another make the word rather a misnomer, and the typical free unicellular organism, as will be seen, is not at all described by the word in its usual non-technical meaning.

Amœboid cells are found in sea and pond water carrying on an independent existence, and, in a dependent form, as to nutriment, in the blood and body fluid of higher animals,

where some of their useful work has already been mentioned. An amœba, as a parasite, is also responsible for a form of disease known as tropical dysentery. ~~Gilled by~~

An amœboid cell is a microscopic mass of semifluid consistency. As in the majority of cases of living cells, about three-fourths to four-fifths of the material of the mass is water, and in this water ~~are contained soluble~~ **NOT EXCHANGEABLE AND** consisting of proteins, ~~NOT EXCHANGEABLE~~ **NOT EXCHANGEABLE** hydrates and other bodies, so as to make a thin mobile jelly-like mass, which also contains certain crystalloids. At rest, it possesses a roughly globular shape, but it is rarely at rest, and is more usually slowly changing its shape by means of slow flowing movements called out by the chemical stimulus of nutrient matter dissolved in the fluid in which it is floating. Such dissolved excitants usually emanate from particles suspended in the fluid, such as debris, or bacteria, and if any such particles near to an amœba which is being observed under a microscope be carefully watched, it will often be noticed that the amœba sends processes out towards them, and finally flows round them and takes them into its mass.

This does not always happen, the determining factor is whether the particle possesses

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anything of nutrient value for the amoeba; other inert particles, as a rule, are left alone.

The particle after being engulfed is acted upon and digested by fluid contained in the amoeba, and when that process is completed, any particles of débris which have accumulated are got rid off by a process of flowing away from them which is the exact opposite of the process of uptake. These two processes of taking in and giving out are called ingestion, and egestion. They can occur apparently at any part of the microscopic mass.

Within the mass, two structures may usually be made out. The first of these is not a universal structure in cells, and is called the cell *vacuole*; it seems to be more devoid of structure and clearer than the rest as if it were more fluid. It slowly varies in size from time to time, and there seem to be streaming movements about it as if it were responsible for movements of fluid and a kind of circulation of dissolved materials and minute suspensory materials within the cell. The second structure, on the contrary, is more granular and solid-looking than the remainder. It is only dimly seen when the cell is alive, but it differs in chemical nature from the rest of the cell contents, as is shown by the fact that when the cell is killed and

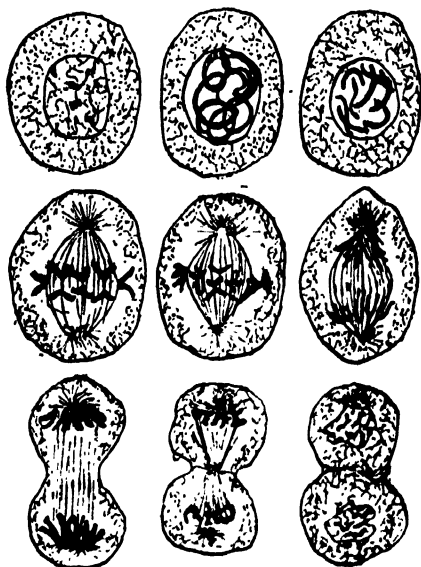


DIAGRAM SHOWING THE CHANGES IN THE NUCLEUS WHEN A CELL DIVIDES TO FORM TWO CELLS. The first sketch shows the resting condition with a reticular nucleus, the next shows the nucleus matter forming a skein. In the third figure the skein has divided into pieces or chromosomes, the fourth figure shows these arranged on the spindle and the two centres or centrosomes. In the fifth figure the chromosomes are splitting lengthwise, and in the sixth these have travelled to the two poles. The remaining figures show the inversion changes and the formation of the two daughter cells.

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treated with stains, it reacts differently from the rest with these chemical substances. A stain which unites strongly with this part usually only stains the other parts lightly or not at all, and a different stain may behave in exactly the reverse manner. This view is confirmed when many other different types of cell than the amoeba are subjected to chemical examination. Every complete and perfect living cell possesses one, or more, of these structures, and it has most important relationships to the processes of cell-reproduction and growth. This part of the cell is called the *nucleus*, and it is the central part, of the whole. When a cell is injured, or mechanically divided, the portion attached to the nucleus, even if it be the smaller part, usually recovers and reproduces a whole cell again, but a part containing no nucleus, or portion of a nucleus, perishes like a branch cut off from a tree. Remarkable changes in the nucleus precede the processes of reproduction in the cell when one cell is about to form two. Before reproduction commences, the nucleus possesses a reticulate or a sponge-like structure, but at a certain stage in the cell-life, some chemical alteration due to a heaping up of energy, causes this structure to alter spontaneously. The peculiar

material of the nucleus then forms itself into a thread-like structure so as to look like a tangled skein of thread, which later shortens and thickens. Then in a most remarkable way the thread divides or becomes cut up into a definite number of short lengths, called chromosomes. The number of these chromosomes is an absolutely fixed and always an even number in every species of higher animal or plant. In man there are, for example, always twenty-four of these chromosomes formed. The chromosomes were formed by equi-distant cuts across the skein, but now each one of these pieces splits *lengthwise*, and, at about the same time, two attraction points are formed some distance apart in the cell, and from these attraction points (or centrosomes) exceedingly fine gossamer-like threads are formed radiating from the centrosome, and attached along the length of each split chromosome. Along these fine threads the split halves of the chromosomes part company from each other, and travel apart from each other, until finally one exact half of the material of the nucleus in the form of split chromosomes is surrounding each centrosome.

An inverse order of affairs now ensues at each of these daughter nuclei, whereby first a skein and then a reticulum is formed.

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Contemporary with these latter changes in the daughter nuclei, the rest of the colloid material of the cell begins to divide simply around the two daughter nuclei, indenting, becoming hour-glass-shaped, and finally dividing into two halves. In this way two cells are formed, which increase in size until once more similar energy conditions arise and lead to a fresh division, initiated and carried through in the same fashion.

There is nowhere outside living matter a set of energy phenomena found to occur *spontaneously* at all resembling this remarkable sequence of changes. Diffusion artefacts bearing an artificial resemblance have been described, but these do not occur naturally, and bear no real analogy to the living processes.

In the processes of cell-reproduction and division there is a type of energy at work never found elsewhere than in living structures.

There is one interesting exception to the process of nuclear-division described above, and that is when the first division of all occurs in the maturation of the ovum, which precedes the sexual production of a new individual in the higher plant or animal. An early stage in the history of the new individual is a union of two cells one from a male and the

other from a female parent. If the fusion of the two nuclei took place, there would obviously be at each generation a doubling of the amount of nuclear matter and twice the normal number of chromosomes. Nature arranges against this by a remarkable preparation of each parental nucleus. In each *first* division which occurs in each parental cell before the male and female elements come in contact, only half the usual number of chromosomes is formed, then for some unknown reason, a re-arranging division occurs with the usual number of chromosomes, but half the amount of material in each one. At each of these preparatory divisions *in the female cell*, one of the two nuclei formed is extruded from the cell and atrophies. The female cell does not divide as a whole in these two divisions: only its nucleus divides. After the completion of this curious process, which is known as maturation, a reduced male nucleus and the reduced female nucleus unite to form a first mixed nucleus to the fertilized ovum, in which the two sexes obviously share equally. The purpose of the rejection of a part of each nucleus has caused much discussion, and is not yet at all clear, but it is probably closely concerned with heredity and species preservation.

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This is another fine example of a type of energy transformation never witnessed anywhere else than in living structures. So is also the long series of co-ordinated cell divisions and reproductions in the growing embryo, and the origin in unfailing sequence from one cell of all the many kinds of cell and tissue found in a higher plant or animal. The fertilized ovum of one mammal is structurally indistinguishable from that of another, and contains in it nothing representative of the many diverse structures that are destined to arise in course of development.

But the colloids possess specific differences, and it is initially inhabited by a form of energy unknown outside life processes, which leads the mazy dance of life from point to point, each new development furnishing a starting point for the next one. A specific colloidal structure, with a definite energy distribution at each stage, forms the opening for the next stage. It has been seen that each structural variation in matter means a different energy distribution, and to deny that the energy distributions in living matter are different in type from those inhabiting inorganic matter would be as absurd as to deny that different energy forms exist in the inorganic world, each characterized by its

own peculiar set of phenomena. No energy exchanges or natural phenomena could exist were there not different inorganic types of energy. For all those changes which affect our senses or our instruments are due to energy transformations from one energy form to another. The words, heat, light, magnetism, electricity, and those terms designating the various forms of radioactivity possess a meaning although all related and all manifestations of physics and chemistry. Electrons, atoms, molecules, colloids, cells are different things, though related to one another. The chemical elements must be recognised as existent—although transmutable. Some term is obviously required applicable to the entirely peculiar set of energy phenomena witnessed in living matter, such as *biotic energy*. Heat energy and electrical energy are mutually transmutable one into the other, yet it is not said that electrical energy is heat or light because these appear when it is transformed. Why, then, should a form of energy such as inhabits living structures be thought to be only a mixture of heat and electricity and chemical energy, because these are observed when it manifests itself? The position which denies the existence of a form of energy

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characteristic of life is one of peculiar absurdity even for the pure mechanician, which can only be explained as a natural reaction from the entirely different mediæval conception of a vital force which worked impossible miracles. As well because of the errors connected with the idea of "phlogiston" might the present ideas regarding "energy" as a whole be scouted.

It is *biotic* energy which guides the development of the ovum, which regulates the exchanges of the cell, and causes such phenomena as nerve impulse, muscular contraction, and gland secretion, and it is a form of energy which arises in colloidal structures, just as magnetism appears in iron, or radio-activity in uranium or radium, and in its manifestations it undergoes exchanges with other forms of energy, in the same manner as these do amongst one another. There are precisely the same criteria for its existence as for the existence of any one of the inorganic energy types, viz., a set of discrete phenomena; and its nature is as mysterious to us as the cause of any one of these inorganic forms about which also we know so little. When we know *why* hydrogen and oxygen unite to form water, then we shall be near to understanding the balance of organic colloids. In fact, the

knowledge may come to us in the reverse order.

With the development of the ovum of higher plant or animal into its myriad brood of different types of cells with correspondingly different functions, the last great stage on our journey of evolution is reached, and we have now to consider some of the energy phenomena which arise at this most complex stage of all, on account of the life, or energy flux, lived in common by these various nations of cells.

The functions served by many of the great systems of tissues of the body, and the co-relationships of these to one another, are so obvious as to require only passing mention. There is the jointed osseous system of bones, joints and ligaments which forms the skeleton, and serves the purposes of preservation of the form of the animal, locomotion, capture and mastication of food, and the performance of skilled manipulations of many kinds. The osseous system is activated by the voluntary muscular system, which in turn is worked by the immense system of nerve cells and their processes (the nerves) connected with brain and spinal cord. Each apparently simple voluntary movement such as those of vision, eating, speaking or writing, is in reality, as shown by Sherrington's researches,

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a brilliantly played piece of biological symphony by hundreds of thousands of nerve cells and muscle cells playing in perfect harmony, and timed sequence of performance. Nutrition absolutely adapted in quality and quantity must be provided for these skilled players, and this provides work for the great digestive and circulatory systems, which also are regulated and controlled by master nerve-cells both of the central nervous system, and of a special nervous system of their own called the sympathetic nervous system. The food must first be rendered soluble by digestive ferments manufactured by special glands, and poured out into mouth, or stomach, or intestine. The soluble chemical products must be built up upon a system for which each type of animal possesses its own plan and secret device, in intestinal absorbing cell, in liver, and in lymph gland, and each such guild or craft of cells knows its own cunning workmanship. The specifically prepared food now chemically built up to the exact chemical pattern, in whatsoever protean form it may chance to have entered the mouth, so that it can form part of the circulating blood, is borne round in endless circuit by the powerful thrusts of the beating heart. By the branching and re-

uniting system of arteries, capillaries, and veins, the life-maintaining fluid is diverted into thousands or even millions of capillary channels, in which it is only separated from the fluid bathing the needy tissues, by thin, transparent, permeable cells compared to the thinness of which the finest tissue paper is as thick as hide. Here the commerce of chemical exchange goes on in a never-closing market. Day or night, asleep or awake, nutriment is taken in and poisonous excretory substances given out; but also all types of beautifully manufactured chemical goods are exchanged. It must not be supposed that nutriment alone is taken and waste returned, in exchange for some single obvious service to the community, such as a muscular contraction, a nervous stimulus given at the proper instant of time, or the elaboration of a digestive secretion.

The classes of cells are greater artists, and take wider interests than this; few of them resemble in narrowness of life and austerity of outlook the so-called human specialist. In nearly every case the cell of a given type possesses what might perhaps be described as a hobby in addition to its more obvious function, and the secret hobby is often more all-important than the obvious day's

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task-work, for in some instances the obvious function may be destroyed without causing death, its place being undertaken vicariously by some other part, but interference with the hobby usually leads to sudden and remarkable death of the whole animal. This will be reverted to later when the other main systems have been mentioned.

The amount of blood flowing to various parts is carefully regulated by a set of nerves, which acting upon circularly arranged muscle-fibres control the diameter, or calibre of the small vessels in a manner much more perfect than the taps on a town water-supply. Not only must food be borne to the cells, oxygen must also be carried, else the cells could not set the energy of the food free. The waste products of the combustion must also be carried away. This office is accomplished by the respiratory system, which carries the gaseous products to and from the lungs in solution or in union with the red colouring pigment of the blood and the proteins, while other solid waste products are removed in solution by the renal excretory system.

Excess of fluid containing waste products, lying between the tissue cells and other constituents, is drained off by a system of fine vessels called the lymphatics, and after

undergoing purification in structures called lymphatic glands, is returned to the venous system by the main lymphatic ducts, the whole forming the lymphatic system.

Early even in the development of the embryo animal, and long before birth, those cells in male or female which are to serve the purpose of carrying on the tide of life into the next generation, by uniting with cells from an individual of the opposite sex, are segregated off into separate organs. During the growth of the young individual these are active all the time. It is a mistake to think they have only become active at puberty. They only become capable of producing active sexual cells at puberty, but long before that period they have been actively exercising secret chemical functions in the body, by means of what are known as internal secretions, which are poured into the blood and, being carried to other parts, stimulate these to develop in definite ways. These activities become enhanced as puberty approaches, and such internal chemical secretions induce and control those secondary sexual changes which outwardly differentiate in increasing degree male and female at this age.

The detailed study of the work of these various co-ordinated systems is the domain

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of the physiologist and bio-chemist, just as the study of their derangements forms the province of bacteriologist and pathologist. Similarly the function of attempting to set right or repair what is wrong, rests with physician or surgeon, while the noblest and as yet far too neglected profession of all is that of the sanitarian or hygienist who is charged with preventing affairs from going wrong. When our social senses as a community become sufficiently developed, the sanitarian turning to practical account the discoveries of the others, will remove for us half the deaths and four-fifths of the misery and human torture which to-day we supinely suffer.

An example has been given above in the case of the reproductive glands, of internal secretion. This is one of the most wonderful discoveries of the past generation. Although the name "internal secretion," and the idea of the course of events was introduced by Brown-Séquard in France, it is largely to the labours of Schäfer and other British physiologists, such as Bayliss and Starling, that we owe many of our more recent advances of knowledge in this entrancingly interesting field of investigation. The chemical substances contained in the internal secretions have

been named *hormones*, or excitants, by Bayliss and Starling. In certain cases the chemists have been able to isolate these hormones, and in one case the chemical constitution is known and the substance has been manufactured artificially in the laboratory. In other cases, and these the majority, they are as yet only known by their definite stimulating action. Quite recently it has been shown that bodies similar in nature to the hormones must be present in our daily diet, or certain typical nutritional diseases are produced. These hormones are not foods in the sense of being necessary to provide energy by their combustion; they are only required in minute amounts as excitants, and in their absence certain very specific effects giving the clinical symptoms of well-known diseases appear. In a liberal and mixed diet all the necessary hormones required from outside are contained. But, when the diet is very restricted, such as the rice diet, used by the Indian coolie, unless the thin brownish layer surrounding the inner white part of the rice be eaten in the daily diet, a disease with marked nervous lesions appears, called *beri-beri*. This disease long puzzled medical scientists, but it is now clearly shown to be caused by the absence from the diet

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of an excitant contained in the outer layer of the rice. Addition of this cleaned-off material in small amounts prevents, or relieves, the disease. A similar condition can be produced in pigeons or fowls fed experimentally on *polished* rice, (as the European product with the outer layer removed is called), and can be relieved immediately by small amounts of extracts of the rice polishings. Infantile scurvy is an example of an infantile disease of our own country produced by restricted diet in a similar manner. As Barlow first showed, it may rapidly be cured by treatment with fresh vegetables such as, the portion of potato lying below the rind, or fresh fruit of different kinds. There is little doubt that rickets and ship's scurvy, which are now being investigated, will prove diseases of a similar kind.

These are examples of external hormones from outside the body required in the daily food, but the body-cells within require to manufacture internal hormones, to establish important correlating functions. If the nervous system be compared to the telephonic or telegraphic system, then these internal hormones might represent the postal system of the body by which one part is kept in touch with another. The chemical intercommunica-

tion of the hormones is slower than that of the nervous system, but more detailed and complete.

There exist in the body a number of glands with no external secretions or obvious uses which were a great mystery to the earlier anatomists and physiologists, who called them "bodies" or "capsules," and left the matter at that. The chief of these are called the suprarenals, the thyroids, the para-thyroids, and the pituitary. It is now known that these are active secreting glands, and in spite of their small size and obscurity of function, are absolutely essential to the life of the animal. Their removal invariably causes death in a few days to a few months' time, and any marked disturbance of their function in the direction either of excess or defect produces profound disease often of a fatal character.

The investigation of the uses of the suprarenals, two minute glands not over an ounce in weight, lying in the body just above the kidneys, but in no functional way connected with them, may be taken briefly as an example. The first step was made by a physician of Guy's Hospital, named Addison, who showed that a disease since called Addison's disease, was related to a diseased condition of the

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suprarenals. This disease shows a peculiar bronzing of the skin occurring in patches, and is accompanied by progressing muscular weakness, listlessness, and eventually extreme lassitude. It is invariably fatal. Next Brown-Séquard showed that the removal of these tiny glands always led to fatal results. This was confirmed by Schäfer and other observers, and the clinical picture is that of an excessively rapid Addison's disease. The discovery was next made by Schäfer and Oliver, that these glands are constantly supplying to the blood a chemical hormone which possesses a tonic or stimulating action upon the heart and arteries, particularly the small arteries, or arterioles, leading to the capillaries. The substance has since been isolated, and is known as *adrenalin*. It has even been prepared artificially, and its chemical constitution is well known. When even a minute amount is injected into a vein, it exercises such a constricting effect upon the muscular coats of the small arteries that the bore is nearly obliterated, and as the heart still goes on pumping with even greater force, the pressure in the arteries may mount to double or, even treble its usual amount. It is obviously the absence of this substance in Addison's disease which gives rise to the

symptoms and leads ultimately to the death of the patient. It is truly wonderful that the secretion of a tiny gland, the total weight of which does not nearly reach one-thousandth part of the body-weight, should produce such a prodigious effect. The chemical balance in the body is a surpassingly beautiful and delicate creation ; there is room for a religion of science in the wonder and admiration of these things.

As an additional example of the practical value accruing incidentally from scientific research, it may be mentioned that the active principle of the suprarenal gland, adrenalin, is one of the most valued aids in the surgery of the nose and throat, from its property of stopping bleeding by chemically occluding small arteries in situations where they cannot be reached to be ligatured.

The thyroids are a pair of glands in the neck situated on each side of the larynx, and of about the same size as the suprarenals. In the normal condition, they are not obvious, as they only fill up the rounding of the contour on each side of what is popularly known as Adam's apple ; but disease sometimes enlarges them, and produces a goitre.

If these glands are deficient at birth, growth of the child both in body and mind becomes

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greatly embarrassed, and the product is a peculiar type of dwarf called a *cretin*, found frequently in certain Alpine valleys. Stray cretins are to be found in all large centres of population, and in a typical cases there can be no failure of recognition. The height is stunted down to four feet or less, the head and face are broad, and on account of failure or misplacement of the natural folds of the skin the features are lacking in expression. The hair and skin are dry and lustreless, and the eyes are dull, the whole indicating even to a lay person a condition of idiocy. And the undeveloped mind is truly indicated by these outward appearances. The hands even are large and clumsy in shape, and the fingers broad and stub-ended. All this change is produced by a failure in the secretion of a small inconspicuous gland in the neck, which in a grown man does not exceed an ounce in weight. Short of complete cretinism, backwardness in intelligence and growth, in many of our mentally defective children are due to diminished thyroid secretion, and such cases show wonderful improvement not only in growth and physical vigour, but in mental intelligence also, when they are put upon a course of treatment with thyroid glands of the sheep. For the active material

does not undergo destruction in the process of digestion. Its exact chemical nature is unknown, but it appears to be a colloidal substance rich in iodine.

When disease causes the secretion to decrease after adult life is reached, as it often does, dwarfing cannot, of course, be produced, but the mental symptoms are the same. The patient loses in intelligence and becomes abnormally forgetful, so that no continuous mental process can be carried out. The mind becomes inert, the heart-beat is slowed, the face becomes vacant and expressionless, and there develops a striking slowness of thought and motion, and a heavy, slow gait. Like the opposed condition of goitre, the disease, known as myxoedema, is much more prevalent amongst women than in men. If the disease be not promptly treated by administration of thyroid gland, the mental symptoms become exaggerated, the patient becomes irritable, and suspicious of the motives of relatives or attendants, and there may be hallucinations leading to dementia. Feeding on thyroid gland is the only really beneficial treatment, and often produces remarkable results.

Sir William Osler describes the results of thyroid treatment in such cases as follows :

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"Our art has made no more brilliant advance than in the cure of these disorders due to disturbed function of the thyroid gland. That we can to-day rescue children otherwise doomed to helpless idiocy; that we can restore to life the hopeless victims of myxoedema, is a triumph of experimental medicine for which we are indebted very largely to Sir Victor Horsley and to his pupil, Murray."

"The results as a rule are most astounding—unparalleled by anything in the whole range of curative measures. Within six weeks a poor, feeble-minded, toadlike caricature of humanity may be restored to mental and bodily health. The skin becomes moist, the pulse rate quickens, and the mental torpor lessens."

In the disease known as exophthalmic goitre, the symptoms are almost the exact antithesis of those above described, and the cause is *excessive* secretion of the active material by a large and active thyroid. The patient is alert, excitable, and vivacious of mind, the heart-beat is rapid, there are fine tremors of the voluntary muscles, and the whole picture is one of nervous over-excitement, which is heightened by a prominent bulging forward of the eyeballs which gives the disease its name. Somewhat similar

temporary disturbances may be induced in normal individuals, by excessive treatment with sheep's thyroid glands.

These results show, as Gley, a prominent French observer on the subject, remarks, that "the genesis and the exercise of the highest faculties of man are conditioned by the simple chemical action of a product of secretion, a fact which should be borne in mind by psychologists."

The pituitary is a still smaller gland than either suprarenals or thyroids, and is a single gland attached to the base of the brain. Its hypertrophy during youth leads to *giantism*, and most giants exhibited at "shows," on examination after death show hypertrophied pituitaries. When the hypertrophy occurs *after* growth of the skeleton is completed, the result is a disease showing remarkable overgrowth of certain bones only, known as *acromegaly*. The overgrowth occurs chiefly in the bones of the hands and feet, and the bones of the face, especially the lower jaw, producing a remarkable and unmistakable appearance. Giantism is a somewhat rare disease, but cases in elderly persons of the partial form are not so infrequent. Small as the pituitary gland is, it is composed of two parts of quite different function. It is only the anterior portion

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which is concerned in regulating osseous growth, the posterior portion secretes a hormone which has a somewhat similar action to the suprarenal, but feebler and differently evoked. As has recently been shown by Schäfer, it also stimulates the secretion both of the kidney and of the active mammary gland.

In addition to these remarkable chemical sympathies of the ductless glands, other glands in the body possessed of ducts such as the pancreas, which produces a powerful digestive secretion, also are found to possess internal secretion. Thus, ligature of the duct of the pancreas so as to stop the action of its secretion, does not cause death. The work of digestion is performed vicariously by other secretions. As much as two-thirds even of the gland *and* the duct may be removed without producing serious symptoms. But, if the remaining third be removed, or if the total gland has been removed in the first instance, then death within two or three weeks, from the severest form of diabetes, is the invariable result.

In severe diabetes in man, the pancreas is often found diseased, although milder diabetes may result from other causes.

These results demonstrate that the pancreas

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in addition to its external obvious secretion which it pours into the intestine, possesses a secret internal secretion which it pours into the blood for the regulation of carbohydrate exchanges in the body.

These instances may suffice to demonstrate the wealth of chemical sympathies existing between the huge nations of living units of different types which constitute our bodies, and the delicacy of structure can be appreciated which makes such highly specific reactions possible. The whole subject is modern, and is as yet by no means exhausted.

CHAPTER X

CYCLIC ACTIVITIES OF LIFE: WAKING AND SLEEPING: FATIGUE AND RECUPERATION

THE living cell may be regarded, from the physico-chemical point of view, as a peculiar energy-transformer, through which a continually varying flux of energy ceaselessly goes on, and the whole life of the cell is an expression of variations and alternations in rates of flow of energy, and of swings in the balance between various forms of energy.

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Just as in the production of electrical energy by means of a dynamo, which is an energy-transformer, there is a conversion of mechanical energy into electrical energy, and this electrical energy shows its peculiar properties by which electricity is characterized and, in turn, according to the transformer through which it is passed, may be turned into various other forms of energy, such as mechanical energy, magnetic energy, heat, light, or chemical energy, so chemical energy in the living cell is converted by the colloidal structure into the peculiar type of energy characteristic of living organisms, which has been called biotic energy, and this biotic energy manifesting its own specific properties in the process, is convertible into mechanical energy, electrical energy, heat energy, or chemical energy.

All energy transformations are oscillatory or phasic in their discharges. Each energy transformer has its phasic period, or revolution time, in which it passes through a cycle or oscillation. This is equally true of the living energy-transformers or living cells, and the period varies from one type of cell to another. As a rule, being dependent as has been seen upon the more complex character of the constituent colloids, the period of oscillation

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is generally slower in organic forms of kinetic energy than in inorganic forms. As a result the phasic discharges become more obvious to the senses, and there is nothing more beautiful than to watch the swing to and fro in measured rhythm of the various life-processes. As long as life lasts there is no complete cessation in the flow of energy, but always in all living things there are alternating periods of activity and repose, of waking and sleeping, of action and reaction, of freshness and fatigue.

Another important point is that in these slower surgings of the life-process, the short simple cycle of inorganic nature is often replaced by a long procession or sequence of events in definite order, and with many members such as is never seen in absence of life. The development of man, or a higher mammal, from the ovum is one example; the ordered sequence of the outburst of seasonal life in the cycle of the year is another; and countless examples of such lengthy cycles where one energy exchange is contingent upon and sequent in time to another, occur in the daily lives of higher plant and animal individuals.

Although the cyclic processes of life demonstrate a longer time-interval throughout, as

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compared with inorganic nature, they vary amongst themselves from a period of several years, as in the growth to maturity of the human individual, to a minute fraction of a second, as in the time of passage of a nervous impulse which occupies not more than the one ten-thousandth part of a second.

Some of the cyclic periods of living cells are so short that their truly cyclical character, and the nature of the alternations, have been missed or mis-stated by physiologists in the past. Conspicuous examples of this are to be found in regard to nervous activity and the rhythmic contractions of cardiac muscle. In nearly every current textbook of physiology the statement will be found, followed by elaborate proofs, that nerve and heart-muscle cannot be fatigued, or are indefatigable, as it is called. The true statement which ought to replace this is, that the cycle of fatigue and recuperation is so rapid that fatigue and recovery occur between each heart-beat, or each nervous impulse.

It has been shown by Schäfer that the nervous impulse sent out to the voluntary muscles is not continuous, but consists of a series of impulses at the rate of ten to twelve per second. Now the period of passage of each of these over any given portion of nerve is

only one ten-thousandth of a second, and on adding up the number of impulses in a second, it is obvious that at most the tissue is only active for twelve ten-thousandths of a second in each second, or for about 0.12 per cent. of the total time. There is thus sufficient interval for recuperation between each period of activity. Even when an electric current of 1000 shocks per second is used as a stimulus, there is ample time between each stimulation for recuperation. At a much higher rate of stimulation than this the nerve tissue solves the problem by ceasing to respond. A strong enough current to light up powerful electric lamps can be sent through the human body if the electric oscillations exceed 30,000 to 40,000 per second, without causing any effect upon the muscles or nerves.

The rate is much slower for the contractions of heart muscle, although still very rapid amongst biological phases. As a result, the sequence of events becomes more obvious. Just after each contraction, so far from not being fatigued, the heart muscle is so completely fatigued that it has what is called a *refractory* period. It relaxes and cannot be caused to contract even by a strong external stimulus. It rapidly, however, loses the products of its fatigue, its colloids re-arrange

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their molecules with great speed, and its energy charges accumulate so rapidly that soon it passes into another phase of activity automatically without any stimulus from without.

The tissues of nerve and heart muscle must inevitably be arranged on the principle of such short periods of fatigue and recuperation. It would be impossible for them to possess the longer periods of other tissues, or recuperation, by sleep, of the body as a whole would become impossible. During the repose of the body as a whole, respiration and circulation must be continued; cessation of either for so short a time even as two minutes would lead to death of the whole organism. So these shorter shifts of labour and rest become developed in the balanced system of their colloids. Apart from the changed time interval, however, the main features of the cycle are the same. Waste products are produced in the active period, cause fatigue, are discharged; and in the resting period, fresh molecular arrangements are made and energy stored for the next active period. In the rhythmically active heart muscle the balance of nutrient matter, of the oxygen used for combustion, and of carbon-dioxide formed in combustion, is set with the

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utmost delicacy; it is only within fairly close limits that the rapid to and fro swing is possible. Appreciable variation in any one of these factors, or the presence of traces only of various drugs such as chloroform, or various cardiac tonics, soon slow or hasten the beat, and a little additional excess (or defect of the normal constituents) stills the organ completely, or sends it into delirium also ending in stoppage.

* Other more slowly oscillating living systems allow greater variations, but each has its limits which must not be surpassed. Fatigue after daily work and the nightly recuperation in sleep are examples of the effects of slower accumulation of waste products. The elimination of these fatigue products, and the building up of fresh reserve stores within the cells during sleep complete the cycle.

Phasic or rhythmic activity in some degree or other, and with widely varying rates, is inherent in the various crystallo-colloids of all living matter. It is seen in the unstriated, or involuntary, muscle of all parts of the body, such as alimentary canal, bladder, uterus, spleen, arterial walls, everywhere with varying rhythm in different situations, according to development and requisite physiological functions. It is seen in all the

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secreting glands, where the precursors of the secretion accumulate during rest, and are discharged on activity, leading to exhaustion which ushers in a new period of rest. Some external stimulus forming an act in a greater cycle in the body usually wakes the gland into activity, but, failing this, if the time-interval becomes too long, it automatically passes into activity and discharges itself.

A most interesting and beautiful example of such a rhythm dependent upon external stimulation under normal conditions, but capable of becoming automatic in absence of the wonted stimulus, or its delayed arrival beyond the accustomed time, is found in the case of the phosphorescent organisms so abundant in our seas especially in the autumn months.

It might be supposed at first thought that these phosphorescent organisms are not observed to emit light during the day because of the presence of sunlight, and that if taken into a dark room, such as is used for photographic purposes, they would be found to phosphoresce just as brilliantly as at night. Such is, however, not the case, not a spark can be elicited from them even by vigorous shaking, so long as there is daylight in the outer world. But if one stands by and

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watches in the dark room, as twilight is falling outside, although the organisms have not been exposed to light all day, one observes the little lamps light up and flash out one by one like coruscating diamonds in the darkness, till the whole dish is studded with flashing and disappearing light, a glorious sight in the darkness and stillness.

At the daybreak, the series of changes are the reverse of those witnessed at dusk ; if the dish containing the organisms be observed in the dark room about an hour before sunrise, it will be seen that at first the organisms are still flashing out brilliantly, but about half an hour before sunrise, the number of flashes begins to diminish rapidly ; at sunrise there are hardly any showing, and half an hour later even violent stirring will not produce a single sparkle. The most remarkable thing of all is that this regular daily phasic action is kept up for as long as fourteen days, by which time the organisms have perished in captivity. Regularly every evening the lights come out, and as regularly every morning they are extinguished, although all the intervening time the tiny living creatures have been kept in darkness.

A similar diurnal rhythm has been observed for shorter periods in plant leaves which alter

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their position at day and night, when the plants have been kept in darkness.

The whole of the physiological and chemical processes of reproduction in the mammalia illustrate the phasic activity of living matter in a most striking fashion. In the lower mammalia, there are the seasonal periods of activity in ordered sequence, the whole reproductive system passes into excitement in its different parts, showing the pre-œstral period, then the active mental and other excitement of the œstrus, followed in turn by the post-œstral period. In the human species, the cycle is even more regular, and is more frequently recurrent.

During gestation the same phasic intervals are seen, as also in post-natal growth, and throughout the whole life of the individual the same phasic repetition is seen constituting the great cycle of life.

In the invertebrata cyclic processes are often shown in a most remarkable way. Mention need only be made of the metamorphoses of the insecta, and the wonderful developmental history of the echinodermata and mollusca. In protozoa also there are the alternations of sexual with asexual (or parthenogenetic) reproduction occurring spontaneously, or in response to environmental changes.

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The seasonal variations in the life cycle of plants yield additional examples, and a great correlation of many life cycles involving several different species of plants and animals in harmonious sequence, is observable in the order of appearance of the minute creatures, in pond and ocean, and upon earth, with the coming of the spring.

Here, then, we stand at the end of our review of inorganic and organic evolution, and of the origin and nature of life. There is continuity and consistency in it all; there is beauty in it and design in it.

. There is a scheme in it all and an eternal purpose which is ever progressing. It means something that this much has been revealed to us, and having once seen it there comes a touch of illumination and faith, that kindles something sacred within the mind akin to reverence and love. One must needs work for the highest and for more knowledge of this revelation, whatever the future may hold in store, for we do not now know how more and more glorious things may yet be.

LIVERPOOL, *November 1st, 1912*

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